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The Effect of Four Mine Spoil Treatments on the Seedling Water Relations of Two Plant Species

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THE EFFECT OF FOUR MINE SPOIL TREATMENTS ON THE SEEDLING WATER RELATIONS OF TWO PLANT SPECIES

by

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of the requirements for the degree

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Lorraine K. Van Kekerix

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ABSTRACT

The Effect of Four Mine Spoil Treatments on the
Seedling Water Relations of Two Plant Species

by

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Surface mines in mountainous areas cause environmental deterioration at lower elevations in the watershed. The most successful long term solution to the downstream problem is revegetation. However, mine spoils are low in essential plant nutrients, have low water holding capacity, and are often acidic. These factors limit plant colonization. Plants must also be adapted to the environmental conditions of high elevations.

At the McLaren Mine, Montana, at 2800 m, it was observed that seedlings on revegetation plots were desiccated, indicating possible water deficits. Field and growth chamber studies were carried out to determine the effects of some spoil ameliorating treatments on leaf water potentials, leaf pressure potentials and seedling development and mortality. Poa alpina L. and Alopecurus pratensis L., the two plant species seeded are successful revegetation species in the area. The four treatments were: 1) a control group with no spoil treatment, 2) peatmoss incorporated into the spoils, 3) a surface mulch of jute net, and 4) peatmoss-plus-jute net.

Results showed a decrease in water stress experienced by plants on plots with spoil ameliorating treatments. The jute net, or peatmoss-plus-jute net treatments were the most effective in reducing water stress. Leaf pressure potential data were extremely variable, making it difficult to determine trends.

In the field seedling mortality was reduced on plots with jute net or peatmoss-plus-jute net. No trends were apparent in the growth chamber study. In both studies seedlings were larger with jute net or peatmoss-plus-jute net treatments.

(60 pages)

INTRODUCTION

The major problem caused by abandoned surface mines in mountainous areas is environmental deterioration at lower elevations in the watershed. High erosion rates lead to increased sediment loads downstream and decreased water quality (Striffler, 1973). Acid runoff from mines and high concentrations of heavy metals in the water are lethal to aquatic organisms and the vegetation along streambanks (Warner, 1973; Johnston et al., 1975).

The most successful long term solution to these downstream problems is revegetation of the spoils. Revegetation is hindered by many interacting conditions on surface mines. The exposed parent materials are low in nutrients essential for plant growth. The coarse spoil texture and lack of organic matter contribute to low cation exchange capacities. In pyritic spoils acid is produced by oxidation of sulfides, and the low pH restricts nutrient availability to, and water absorption by plants. Toxic levels of heavy metals such as copper, iron, and aluminum can prevent plant growth and establishment (Antonovics et al., 1971).

The bare spoils have a larger daily temperature fluctuation than vegetated areas (Schramm, 1966). The coarse texture of the spoils and low levels of organic matter contribute to low water holding capacity and rapid rates of drying. In addition to the conditions on the mine, plants must be adapted to the short growing season, high solar radiation loads, congeliturbation, and high winds of high elevation sites (Billings, 1974).

Amelioration of conditions on surface mines is necessary for revegetation. Application of fertilizers has been demonstrated to be essential in many areas (Dunbar and Adams, 1972; Vogel and Berg, 1973; Johnston et al., 1975). Application of lime has improved yields in acid areas (Chadwick, 1973; Dunbar, 1974), and mulches have been used to improve spoil water status (Gregg, 1976).

Observations of plots established at the McLaren Mine in southern Montana in 1974, revealed fewer plants on plots without fertilizer (Brown et al., 1976). Many of the seedlings were desiccated, indicating possible water deficits. Since water stress seems to be a problem in seedling establishment, this study was conducted to quantify the effects of a few spoil treatments in reducing plant water stress. Peatmoss and jute net are commonly used treatments. Peatmoss has been used to increase spoil water holding capacity, and jute net has been used to reduce surface drying (Gregg, 1976).

If drought stress is indeed a limiting factor in seedling establishment, a measure of relative drought resistance is desirable. The relationship between total leaf water potential and apparent leaf pressure potential has been proposed by Brown (1974) as a measure of relative drought resistance.

Previous revegetation trials on high-elevation areas of Montana have shown that _Poa alpina_ L., and _Alopecurus pratensis_ L. are important revegetation species. _Alopecurus_ is a perennial, cool season bunchgrass, native to Eurasia (Phillips Petroleum Co., 1971). In its native habitat it grows best in swampy fertile places. In the western United States it is used as a pasture species. _Poa_ is also a perennial bunchgrass and is native to subalpine and alpine regions of the Northern hemisphere (Hitchcock, 1950).

Two studies were developed to aid in future revegetation efforts. The effects of peatmoss and jute net on plant water status were tested in the growth chamber and in the field. Growth chamber studies are often more convenient and more economical to conduct than field studies. Comparisons of field and growth chamber tests were made to determine if growth chamber results could be applied to field conditions.

OBJECTIVES AND HYPOTHESES

The first objective of the study was to determine to what extent soil amendments and surface mulches ameliorated seedling water stress. A field study and a growth chamber study were conducted to determine the effects of four treatments on leaf water potential. These studies tested the hypothesis that seedlings on spoils with an organic matter amendment and a surface mulch will be subjected to less water stress than seedlings on untreated spoils.

The second objective of the study was to determine the relationship between apparent leaf pressure potential and leaf water potential for each species in both the field and growth chamber. Leaf water potential and apparent leaf pressure potential were obtained for samples of Poa and Alopecurus. These experiments tested the hypothesis that apparent leaf pressure potential vs. leaf water potential regression lines differ between species.

The third objective of the study was to determine the mortality of seedlings as influenced by soil treatments. The hypothesis tested was that seedling mortality will be lower on spoil materials with an organic matter amendment and a surface mulch than on untreated spoils.

STUDY SITE DESCRIPTION

The field study was conducted at the McLaren Mine ($109^{o}59'$ W, $45^{o}04'$ N) at 2800 m, located in the Cooke City Mining District on the southern edge of the Beartooth Plateau, in Park County southern Montana. The highly mineralized zones lie on the flanks of the main uplift of the Beartooth Plateau. The Cooke City ore body is a mineralized hydrothermal pyritized copper deposit (Loverling, 1929) and the primary minerals of economic value are gold, silver, and copper.

Mining activities have taken place in the Cooke City area since the 1880's (Glidden, 1976). The McLaren Mine was operated as a shallow open pit mine until it was abandoned in the early 1950's. However, there is still mineral exploration at the mine site today.

At higher elevations, the Beartooth Plateau is characterized by short growing seasons of 60 to 70 days, with low summer temperatures, and relatively high solar radiation (Johnston et al., 1975). Annual precipitation occurs mostly during the winter, September to July, and is estimated to be between 1100 and 1500 mm (Johnston et al., 1975). Localized nature of some storms causes precipitation to vary from site to site. The plant communities of undisturbed alpine areas on the Beartooth Plateau, have been described by Johnson and Billings (1962).

The study plots, 0.5 m^2 in size, are located on a southwest facing slope on a relatively horizontal old roadbed. The layout of the plots is shown in Figure 1. Spoil analyses from samples collected at the end of the field season are presented in Table 1.

Figure 1. Plot layout for the seedling water relations study at the McLaren Mine. Plot size is 0.5 X 1.0 m. The following symbols are used: _Alopecurus pratensis_ = ; _Poa alpina_ = ; Control = C; Peatmoss = P; Jute net = J; Peatmoss-plus-jute net = P + J; Soil water potential measurements = S; Tensiometer measurements = T.

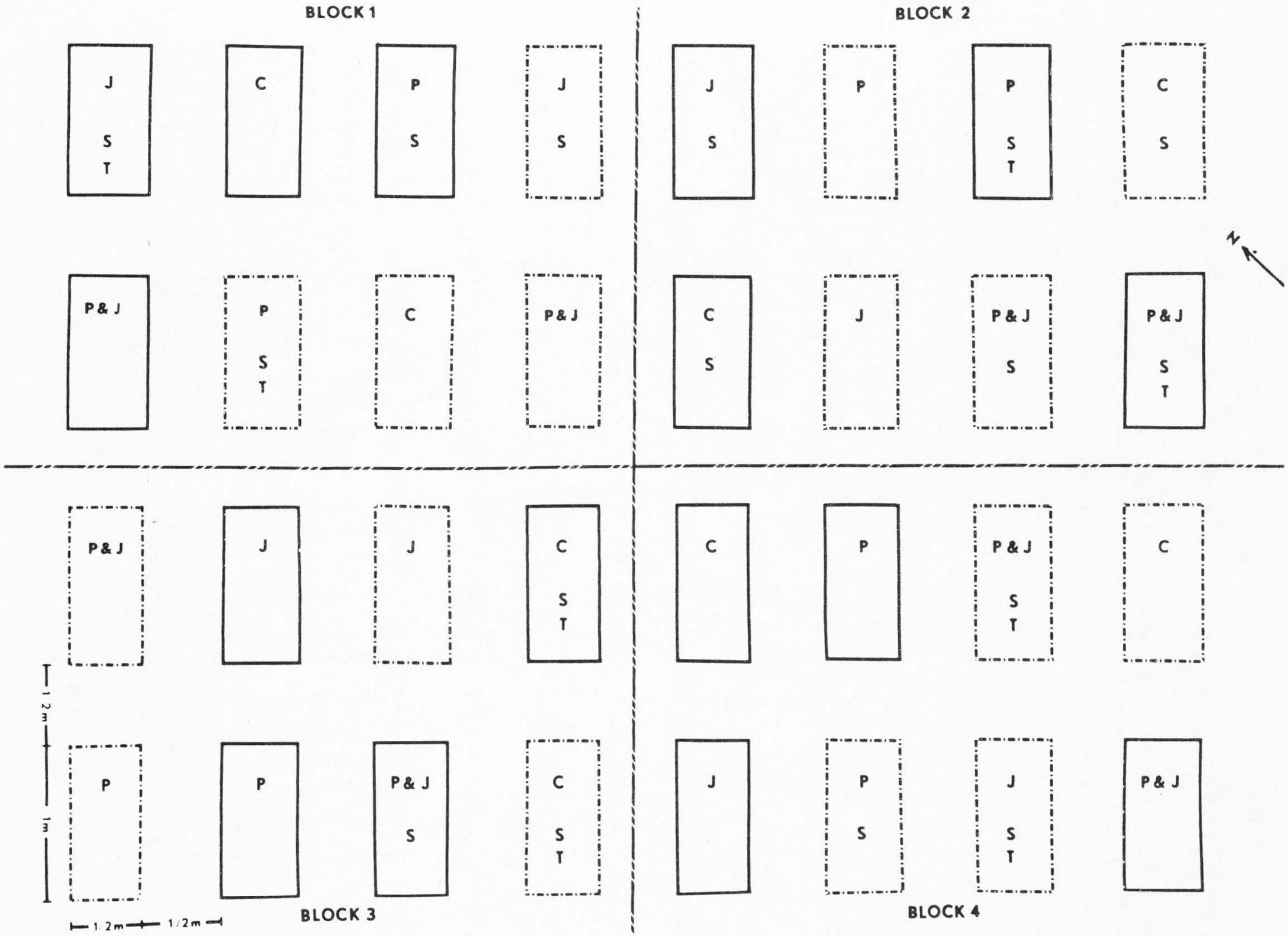

BLOCK 1
J S T
C
P S
J S
P & J
P S T
C
P & J
BLOCK 2
J S
P
P S T
C S
C S
J
P & J S
P & J S T
N
P & J
J
J
C S T
P
P
P & J S
C S T
BLOCK 3
C
P
P & J S T
C
J
P S
J S T
P & J
BLOCK 4
1.2m
1m
1.2m
1/2m

Table 1. Analyses of spoils collected on the McLaren Mine at the end of the field season, September, 1976

Sample Location	pH	EC_e	Estimated Texture	% Coarse Fragments	NH_4OAC Extract K	Ca	Mg	% P Total	ppm Avail. P	meq/ℓ SO_4
Roadbed	1.7	9.4	CL	72	.1	1.4	3.3	.05	6.7	523
Seedling Plot	1.7	13.4	CL	73	.09	3.4	3.0	.04	7.2	414

Sample Location	Fe	DPTA ppm Zn	Mn	Cu	ppm H_2O soluble Al	Cu	meq/100 g CEC	Sat. %	% N	NO_3-N
Roadbed	1250	7.4	10.8	26.5	390	53.3	13.3	33.7	.02	0.3
Seedling Plot	916	5.2	12.0	27.9	430	59.0	13.3	32.8	.02	0.1

METHODS

Field Study

At the McLaren Mine snowmelt is generally not complete until August 1. Spring-seeded plots were established at the mine on July 6 and 7, 1976. The study site was on a flat portion of an abandoned roadbed selected to minimize slope and exposure differences. The physical and chemical characteristics of the site's spoils (Table 1), are representative of the majority of overburden materials on the mine (Brown et al., 1976). Non-acid snowmelt streams near the site were used as a supplemental water supply.

Design

A completely randomized block design, with four blocks of eight plots, was used (Figure 1). The design was chosen to minimize differences due to the variable nature of the spoils. Two plant species *Poa alpina* L., a native, and *Alopecurus pratensis* L. 'Garrison', a commercially available species, were seeded. *Poa* seed was collected on the Beartooth Plateau in 1974; *Alopecurus* seed was obtained from Northrup-King Co., Salt Lake City, Utah in 1976. The four spoil treatments were: 1) a control group with no treatment, 2) peatmoss incorporated into the spoils, 3) a surface mulch of jute net, and 4) peatmoss-plus-jute net.

Site preparation

Snow was shoveled off the site, large rocks were removed, and the site was leveled. The soil was then loosened to a depth of 10 cm. The pH was measured with a portable meter at several locations on the site, using a volumetric 1:1 mixture of soil and distilled water. All pH measurements at the time of plot establishment were within the range of 2.8 to 3.0. Hydrated lime was applied with a drop spreader, and worked into the spoils to a depth of 10 cm with pulaskis, to raise the pH to a value of 6.5. At this site 12.0 kg of lime was required to increase the pH to 6.5.

Individual 0.5 X 1.0 m plots were staked out, and treatments were applied according to the completely randomized block design. All plots received 18:46:10 NPK ratio fertilizer at an equivalent rate of 111 kg of nitrogen per hectare, worked in to a depth of 10 cm. Peatmoss was applied, where appropriate, at 10% by volume (5000 g per plot) and worked in to a depth of 10 cm.

Seeding rate was established by laboratory germination trials, and the low emergence rates observed at the McLaren Mine in previous years (Brown et al., 1976). Germination of *Alopecurus* and *Poa* seeds on filter paper was 60% and 27% respectively. On the basis of previous observations it was expected that only 25% of the seedlings germinating in the laboratory would emerge in the field. To produce 1200 seedlings per plot, 5.0 g of *Alopecurus* seeds (1600 seeds per g), or 5.1 g of *Poa* seeds (3300 seeds per g) were scattered, based on the calculations described above. Seeds were broadcast evenly over the surface, raked in approximately 0.5 cm, and packed. Jute net was laid over the appropriate plots, and weighed down outside the plot boundaries with rocks. Approximately 27 cm of snow was piled on the plots to simulate natural conditions, and provide the seedlings with water.

Since there was little precipitation in July, plots were sprinkled with water from a nearby non-acid snowmelt stream, until plants reached the second leaf stage. This insured that plants would be available for experiments when they reached the second leaf stage. Generally, plots received 0.25 cm of water per day, when no precipitation occurred.

Data collection procedures

Sampling began on August 9, 1976 when plants reached the second leaf stage. Samples were taken between 1400 and 1600 hours daily, the time of maximum water stress. To measure plant water potential, several seedling shoots were placed in a equilibration chamber with an attached psychrometer. The equilibration unit was then placed in a water bath without temperature regulation, at approximately 25^{o} C, to equilibrate for two hours before readings were taken. To obtain values for the osmotic plus matric components of leaf water potential, the chambers were frozen in liquid nitrogen to kill the plant tissue (Brown, 1974). The chambers were slowly thawed at room temperature, and reequilibrated for two hours in the water bath before the second psychrometer readings were taken. Apparent leaf pressure potential was obtained as the difference between leaf water potential and the osmotic plus matric components of leaf water potential.

In order to estimate soil water potentials a soil sample from 2.5 - 5.0 cm was taken daily from the edge of 16 plots. A mixed subsample was placed in an equilibration chamber with an attached psychrometer, placed in a water bath, and read the next morning.

A 10 X 40 cm subplot centered within each plot was used to determine seedling development, density, and mortality. Leaf water potential measurements were not taken from the subplots because these measurements required destructive sampling. The seedlings were measured at weekly intervals. Number of live plants, number of dead plants, leaf number of the majority of plants, and the range of heights of plants with the most common leaf number were recorded.

Apparatus. All psychrometers used in this study were Peltier double junction thermocouple psychrometers, as described in Van Havern and Brown (1972). Psychrometers were attached to Swagelok brand tube fittings with caps. This unit is a small water tight equilibration chamber. The psychrometers were read with an SB-600 psychrometer readout meter. The daily soil samples were taken with a 1.9 cm diameter soil corer.

Growth Chamber Study

Water relations of *Poa* and *Alopecurus* were also studied under controlled conditions, using the same treatments as in the field.

Preparation

McLaren Mine spoils were sieved to 2 mm, and then lime, fertilizer, and peatmoss were added at the same rates used in the field study. The mixtures were then placed in 1 liter plastic pots with no drainage holes. The seeding rate needed to produce 100 seedlings per pot was calculated to be 0.1 g of *Poa* or *Alopecurus* seeds. The seeds were covered with 0.5 cm of sieved spoils. Jute netting was applied to the appropriate pots. There were four replications of each species-treatment combination.

In the greenhouse the pots received a 14-hour photoperiod, with supplemental flourescent and incandescent lighting in the evening.

Pots were watered with deionized water, and kept in a nonstressed condition until water potential studies began. Pots were kept in the greenhouse until seedlings reached the second leaf stage.

When the second leaf emerged, pots were placed in the growth chamber. Plants were allowed to equilibrate for 48 hours before sampling started. The growth chamber was programmed for a 14-hour light period at 27^{o} C, and a 10-hour dark period at 21^{o} C. There was no humidity control; relative humidities for the light period varied from 25-35%, and for the dark period they varied from 43-68%. The lights turned on and off sequentially. The bank of incandescent lights was turned on after both banks of flourescent lights, and turned off before both banks of flourescent lights. The time interval between the activation of each light bank was 30 minutes.

Data collection procedures

The drying cycle was initiated after the 48-hour equilibration period by withholding water. Daily leaf water potential and its components were obtained as described in the field study methods. A soil core was removed from 3.7 cm below the soil surface of each pot, and placed in an equilibration chamber with an attached psychrometer, to obtain daily soil water potential measurements.

A 10 cm^2 subplot in the center of each pot was reserved for measurements of seedlings at the beginning and end of the drying cycle. Measurements taken are described in the field study methods.

Apparatus. The psychrometers and equilibration chambers used in the growth chamber study were described in field study apparatus. The soil corer used was 5 mm in diameter.

RESULTS

Field Study

Leaf water potentials

Mean leaf water potentials for both the field season and more than two days without precipitation were most negative on plots with no treatment, Table 2. Plants on plots with jute net or peatmoss-plus jute-net had the least negative mean leaf water potential readings. The *Poa* control group had the most negative mean leaf water potential of -19.6 bars. Analysis of variance was not run on the means because the different sample sizes almost certainly had unequal variances.

The mean daily leaf water potentials over the course of the season are presented in Figures 2 and 3. The standard error bars indicate the large range of measured leaf water potential values. On any day there was usually a difference in mean leaf water potential between the control group and the peatmoss-plus-jute net treatment. The variability in the data seems to increase from August 31 to September 6, when no precipitation occurred. There were often not enough seedlings to sample on *Poa* plots with no treatment or peatmoss.

Leaf pressure potentials

Predicted leaf pressure potentials of 0 occurred at leaf water potentials of -20.4 bars and -16.3 bars for *Alopecurus* and *Poa* respectively. Leaf water potential vs. leaf pressure potential regression lines are in Figure 4. The F test for the comparison of means showed the difference between the predicted leaf pressure potentials of 0 to be

Table 2. Mean leaf water potentials and mean apparent pressure potentials of field study data for each species-treatment combination. The number of replicates for each mean varies from 22 to 91.

			All season		More than two days without precipitation	
Species	Treatment	Variable	Leaf water potential	Apparent pressure potential	Leaf water potential	Apparent pressure potential
Alopecurus	Control	Mean	-15.3	2.2	-22.7	-3.4
		Std. error	.8	.7	2.8	2.4
		± std. error	-14.5 to -16.1	1.5 to 2.9	-19.9 to -25.5	-1.0 to -5.8
Alopecurus	Peatmoss	Mean	-13.3	2.7	-16.0	-1.8
		Std. error	.7	.6	2.6	1.9
		± std. error	-12.6 to -14.0	1.9 to 3.3	-14.4 to -18.6	0.1 to -3.7
Alopecurus	Jute net	Mean	-12.2	2.8	-19.8	-3.7
		Std. error	.7	.6	3.0	2.6
		± std. error	-11.5 to -12.9	2.2 to 3.4	-16.8 to -22.8	-1.1 to -6.3
Alopecurus	Peatmoss + jute net	Mean	-11.0	3.0	-13.3	0.6
		Std. error	.7	.3	2.8	3.1
		± std. error	-10.3 to -11.7	2.7 to 3.3	-10.5 to -16.1	-2.5 to 3.7
Poa	Control	Mean	-19.6	-1.1	-25.4	-1.7
		Std. error	1.5	1.4	2.8	2.2
		± std. error	-18.1 to -21.1	-2.5 to 0.3	-22.6 to -28.2	-3.9 to 0.5
Poa	Peatmoss	Mean	-15.6	3.7	-22.7	-8.5
		Std. error	1.0	.8	2.1	5.1
		± std. error	-14.6 to -16.6	2.9 to 4.5	-24.8 to -20.6	-3.1 to -13.6
Poa	Jute net	Mean	-11.3	2.5	-14.5	-3.0
		Std. error	1.0	.6	4.9	2.4
		± std. error	-10.3 to -12.3	1.9 to 3.1	-9.6 to -19.4	-0.6 to -5.4
Poa	Peatmoss + jute net	Mean	-11.5	3.6	-18.7	-0.8
		Std. error	.6	.5	2.9	1.3
		± std. error	-10.9 to -12.1	3.1 to 4.1	-15.8 to -21.6	-2.1 to 0.5

Figure 2. Mean daily field leaf water potentials with associated standard errors for *Alopecurus pratensis*, and the precipitation record for the field season. The number of replicates for each mean varies from 1 to 4. The following abbreviations are used: *Alopecurus pratensis* = Alo; Control = C; Peatmoss = P; Jute net = J; Peatmoss-plus-jute net = P + J.

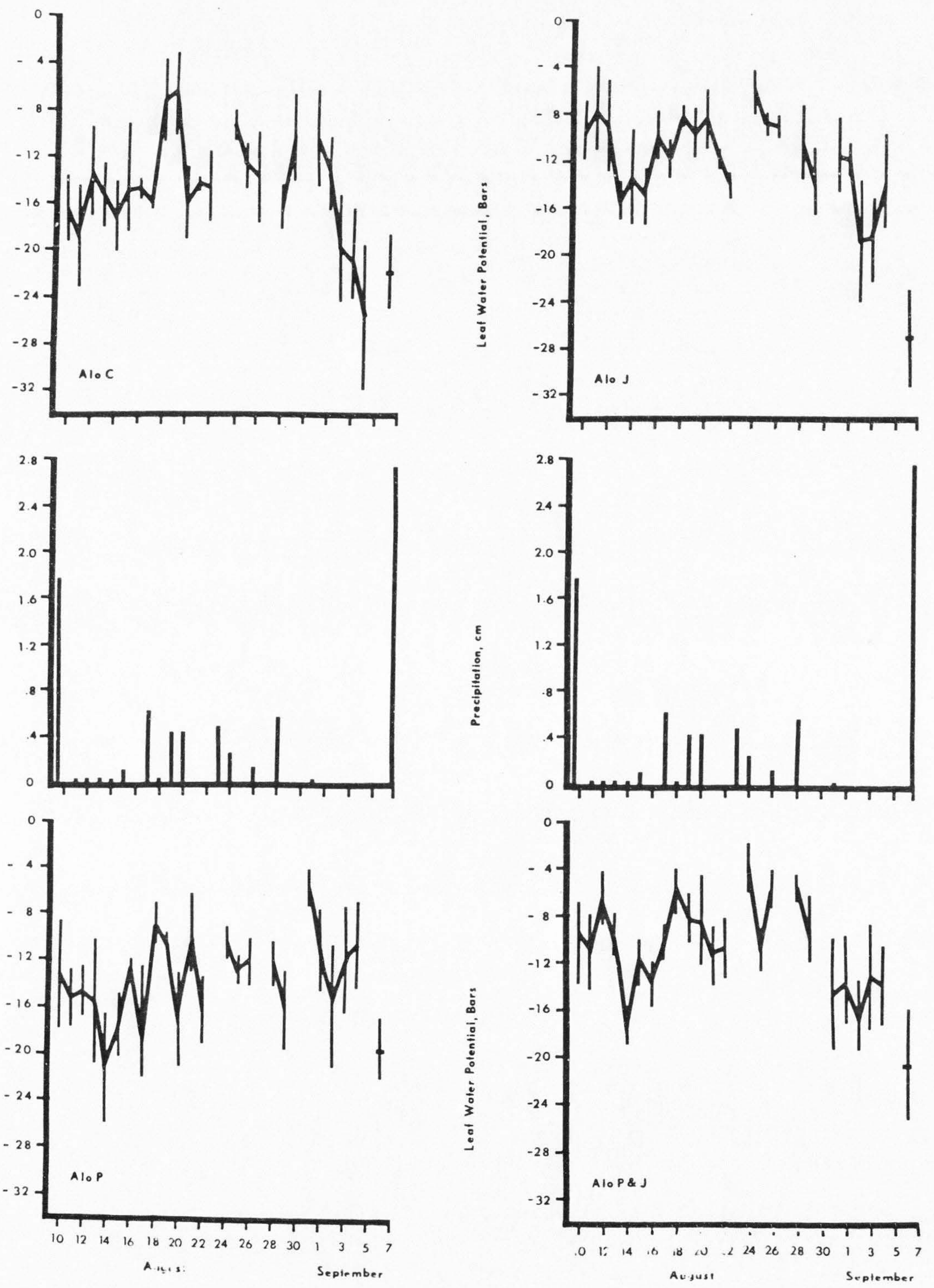

Alo C
Alo J
Leaf Water Potential, Bars
Precipitation, cm
Alo P
Alo P & J
10 12 14 16 18 20 22 24 26 28 30 1 3 5 7
August
September

Figure 3. Mean daily field leaf water potentials with associated standard errors for *Poa alpina*, and the precipitation record for the field season. The number of replicates for each mean varies from 1 to 4. The following abbreviations are used: *Poa alpina* = Poa; Control = C; Peatmoss = P; Jute net = J; Peatmoss-plus-jute net = P + J.

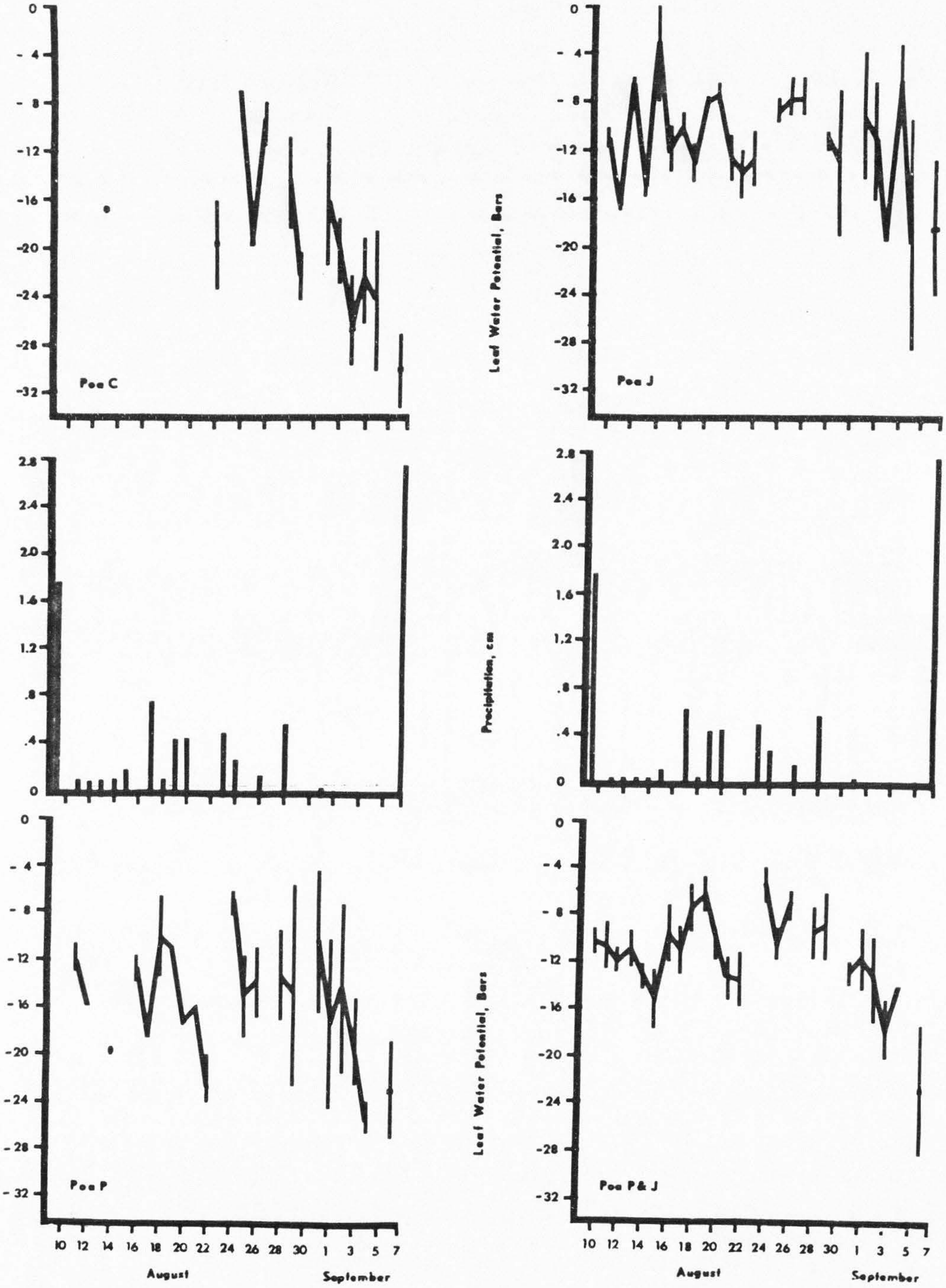
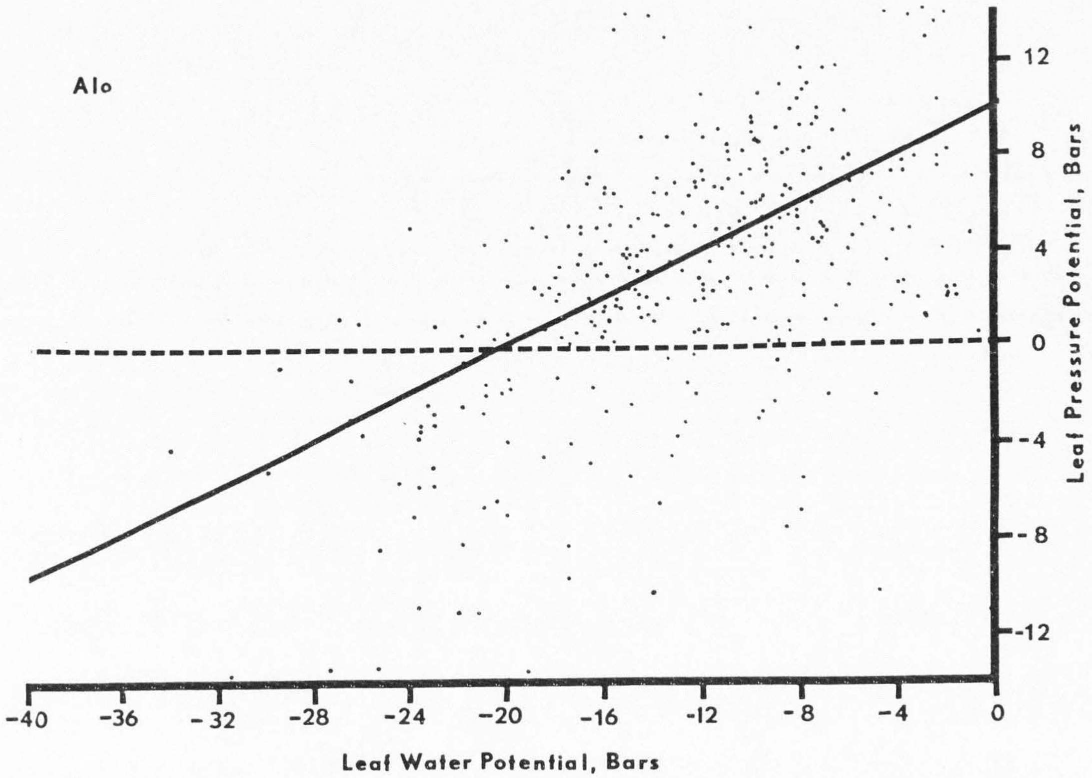
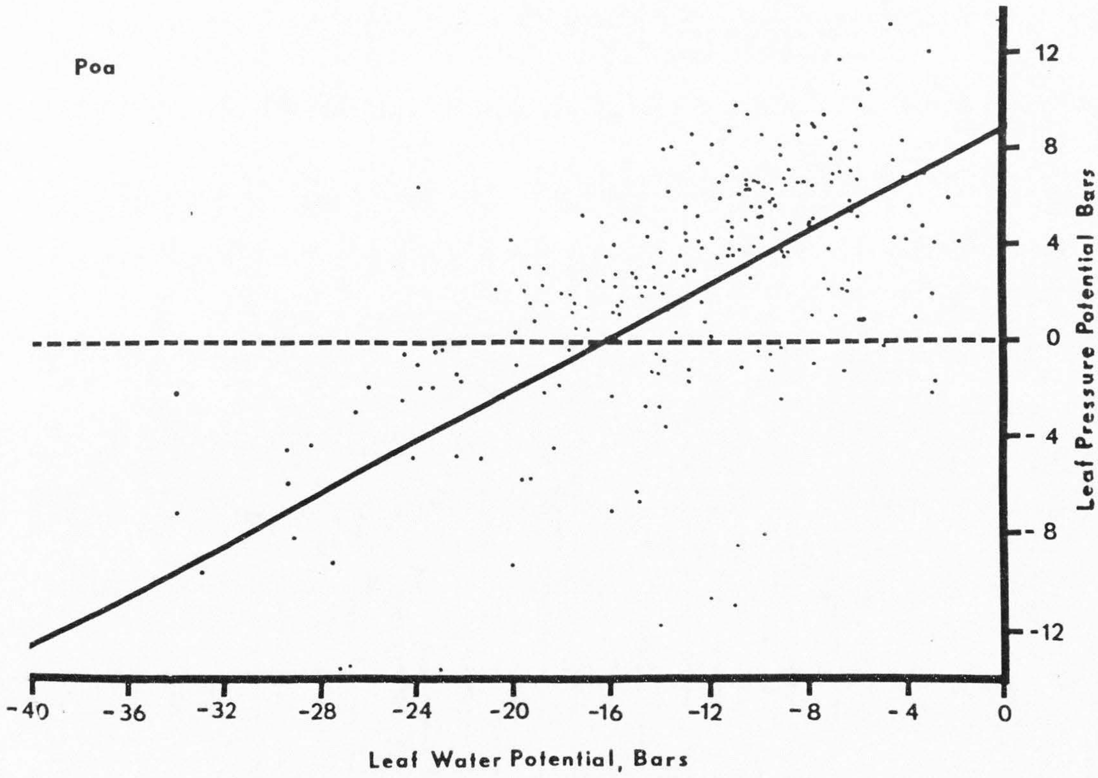

Leaf Water Potential, Bars
Precipitation, cm
Leaf Water Potential, Bars
Poa C
Poa J
Poa P
Poa P& J
10 12 14 16 18 20 22 24 26 28 30 1 3 5 7
August
September

Figure 4. Field leaf water potential vs. apparent leaf pressure potential linear regressions for all treatments. The *Alopecurus pratensis* (Alo) regression line crosses apparent leaf pressure potential of 0 at -20.4 bars leaf water potential, $r^2 = .38$. The *Poa alpina* (Poa) regression line crosses apparent leaf pressure potential of 0 at -16.3 bars leaf water potential, $r^2 = .32$. The difference in leaf pressure potential of 0 is significant at the 1 percent level.


Alo
Leaf Pressure Potential, Bars
12
8
4
0
-4
-8
-12
-40
-36
-32
-28
-24
-20
-16
-12
-8
-4
0
Leaf Water Potential, Bars


Poa
Leaf Pressure Potential Bars
12
8
4
0
-4
-8
-12
-40
-36
-32
-28
-24
-20
-16
-12
-8
-4
0
Leaf Water Potential, Bars

significant at the 1 percent level (Neder and Wasserman, 1974; Graybill, 1976).

When plants did not receive water for more than two days, leaf pressure potentials for plants in the control group approached 0. Plants on control plots generally had more negative mean leaf pressure potentials than plants on plots with the other treatments, as seen in Table 2.

Seedling development, density and mortality

Measurements of seedlings on subplots on August 30, 1976 are presented in Table 3. Analysis of variance of means for each species-treatment combination was run to determine significant differences. There was no difference between replications. For number of live plants there were significant differences between treatments, and due to species-treatment interactions. *Poa* exhibited a response to treatments more clearly than *Alopecurus*. According to the seeding rate calculations there should be 96 seedlings emerging on each subplot. *Alopecurus* consistently had more than 96 plants on each subplot. The number of *Poa* seedlings which emerged was less than 96 seedlings per subplot unless treatments of jute net or peatmoss-plus-jute net were applied.

There were fewer dead *Poa* plants than *Alopecurus* plants. The number of dead plants was significantly different at the 1 percent level. The ratio of dead plants to dead plus live plants was generally lower for *Poa* than for *Alopecurus*. Number of leaves, and minimum and maximum heights of plants with the most common number of leaves differed

Table 3. Means of seedling measurements taken in the field on August 30, 1976. Abbreviations are as follows: Alopecurus pratensis = Alo; Poa alpina = Poa; Control group = C; Peatmoss = P; Jute net = J; Peatmoss + jute net = P + J.

	Group	Number of live plants	Number of dead plants	Dead/ live + dead	Minimum plant height (cm)	Maximum plant height (cm)	Most common number of leaves
Species			**		**	**	**
	Poa	136.2	8.3	0.05	0.8	1.2	2.2
	Alo	176.4	38.3	0.18	1.3	2.5	2.9
Treatments		*					
	C	110.6	20.3	0.16	1.0	1.7	2.4
	P	111.5	25.4	0.19	0.9	1.5	2.4
	J	185.5	14.6	0.07	1.2	2.0	2.9
	P + J	217.0	19.9	0.08	1.1	2.1	2.6
Species-treatment interactions		*	*				
	Poa C	47.5	5.3	0.1	0.6	1.0	1.8
	Poa P	65.3	8.3	0.11	0.8	1.0	2.0
	Poa J	153.5	14.5	0.09	0.9	1.3	2.8
	Poa P + J	278.5	5.0	0.02	0.8	1.4	2.3
	Alo C	173.8	35.3	0.17	1.4	2.4	3.0
	Alo P	157.8	42.5	0.21	1.1	2.1	2.8
	Alo J	217.5	14.8	0.06	1.6	2.8	3.0
	Alo P + J	156.8	34.8	0.18	1.4	2.8	3.0

**Significant at the 1 percent level
*Significant at the 10 percent level

significantly between species. *Alopecurus* had more leaves, and both minimum and maximum plant heights were greater than for *Poa*.

Soil water potentials

Several soil sample water potential measurements were more negative than the corresponding leaf water potential measurements (Appendix A). In multiple regressions run for each species-treatment combination, soil sample water potential measurements explained very little of the variation in leaf water potential measurements, as seen in Table 4.

Tensiometers, measuring soil water potentials at a depth of 7.5 cm, registered soil water potentials drier than -1 bar only a few days during the season. This indicates that water was held fairly near the soil surface. Some plots always had wetter readings than the other plots. This seemed to be due to tensiometer location, rather than to the effect of spoil treatments.

Growth Chamber Study

Leaf water potentials

As in the field study, mean leaf water potentials were most negative for control group plants, and least negative for plants with jute net or peatmoss-plus-jute net (Table 5). However, in the growth chamber the *Alopecurus* control group had the lowest mean leaf water potential, -20.6 bars, the reverse of field study findings

Mean daily leaf water potentials during the drying cycle are in Figures 5 and 6. There are usually daily differences in mean leaf water potentials between the control group and peatmoss-plus-jute net treatment. Variability in the data also seems to increase as the dry-

Table 4. Stepwise multiple regression of field data for each species-treatment combination. Leaf water potential (dependent variable) vs. relative humidity, air temperature, amount of precipitation, days since precipitation, and soil water potential (independent variables). The independent variable explaining the least amount of variation in leaf water potential is deleted first. The r^2 for the final independent variable in the equation is given.

Alopecurus pratensis

Control	Peatmoss	Jute net	Peatmoss-plus-jute net
Degrees of freedom = 22	Degrees of freedom = 32	Degrees of freedom = 26	Degrees of freedom = 22
Total r^2 = .27	Total r^2 = .1	Total r^2 = .34	Total r^2 = .32
Order deleted	Order deleted	Order deleted	Order deleted
soil water potential	air temperature	amount precip.	soil water potential
relative humidity	relative humidity	days since precip.	relative humidity
amount precip.	soil water potential	relative humidity	amount precip.
air temperature	days since precip.	air temperature	air temperature
days since precip.	amount precip.	soil water potential	days since precip.
r^2 = .17	r^2 = .05	r^2 = .26	r^2 = .2

Poa alpina

Control	Peatmoss	Jute net	Peatmoss-plus-jute net
Degrees of freedom = 2	Degrees of freedom = 12	Degrees of freedom = 19	Degrees of freedom = 28
Total r^2 = .99	Total r^2 = .27	Total r^2 = .31	Total r^2 = .37
Order deleted	Order deleted	Order deleted	Order deleted
days since precip.	amount precip.	relative humidity	soil water potential
soil water potential	relative humidity	soil water potential	relative humidity
air temperature	soil water potential	amount precip.	amount precip.
amount precip.	days since precip.	air temperature	days since precip.
r^2 = .57	r^2 = .12	r^2 = .22	r^2 = .2

Table 5. Mean leaf water potentials and mean apparent pressure potentials of growth chamber study data for each species-treatment combination. The number of replicates for each mean varies from 14-17.

			All data		More than two days without precipitation	
Species	Treatment	Variable	Leaf water potential	Apparent pressure potential	Leaf water potential	Apparent pressure potential
Alopecurus	Control	Mean	-20.6	0.2	-25.1	-0.8
		Std. error	2.9	0.9	3.9	1.2
		± std. error	-17.7 to -23.7	-0.7 to 1.1	-21.2 to -29.0	-2.0 to 0.4
Alopecurus	Peatmoss	Mean	-18.5	0.0	-21.9	-1.0
		Std. error	2.1	1.0	2.8	1.6
		± std. error	-16.4 to -20.6	-1.0 to 1.0	-19.1 to -24.7	-2.6 to 0.6
Alopecurus	Jute net	Mean	-13.7	4.5	-16.3	3.3
		Std. error	2.6	1.2	5.0	1.7
		± std. error	-11.1 to -16.3	3.3 to 5.7	-11.3 to -21.3	1.6 to 5.0
Alopecurus	Peatmoss + jute net	Mean	-14.1	2.9	-19.3	1.8
		Std. error	2.2	1.0	2.7	1.6
		± std. error	-11.9 to -16.3	1.9 to 3.9	-16.7 to -22.0	0.2 to 3.4
Poa	Control	Mean	-18.5	-1.4	-21.3	-2.5
		Std. error	1.7	1.2	2.2	1.6
		± std. error	-16.8 to -20.2	-0.2 to -2.6	-19.1 to -23.5	-0.9 to -4.1
Poa	Peatmoss	Mean	-16.1	-1.4	-21.0	-3.3
		Std. error	2.7	1.2	3.5	1.4
		± std. error	-13.4 to -18.7	-0.2 to -2.6	-17.5 to -24.5	-1.9 to -4.7
Poa	Jute net	Mean	-12.5	6.5	-14.3	0.4
		Std. error	1.9	1.8	2.7	3.0
		± std. error	-10.6 to -14.4	4.7 to 8.3	-11.6 to -17.0	-2.6 to 3.4
Poa	Peatmoss + jute net	Mean	-13.8	1.0	-15.0	0.6
		Std. error	1.7	0.8	2.0	1.0
		± std. error	-11.1 to 15.5	0.2 to 1.8	-13.0 to -17.0	-0.4 to 1.6

Figure 5. Mean daily growth chamber water potentials with associated standard errors for Alopecurus pratensis during the drying cycle. The number of replicates for each mean varies from 2 to 4. The following abbreviations are used: Alopecurus pratensis = Alo; Control = C; Peatmoss = P; Jute net = J; Peatmoss plus-jute-net = P + J.

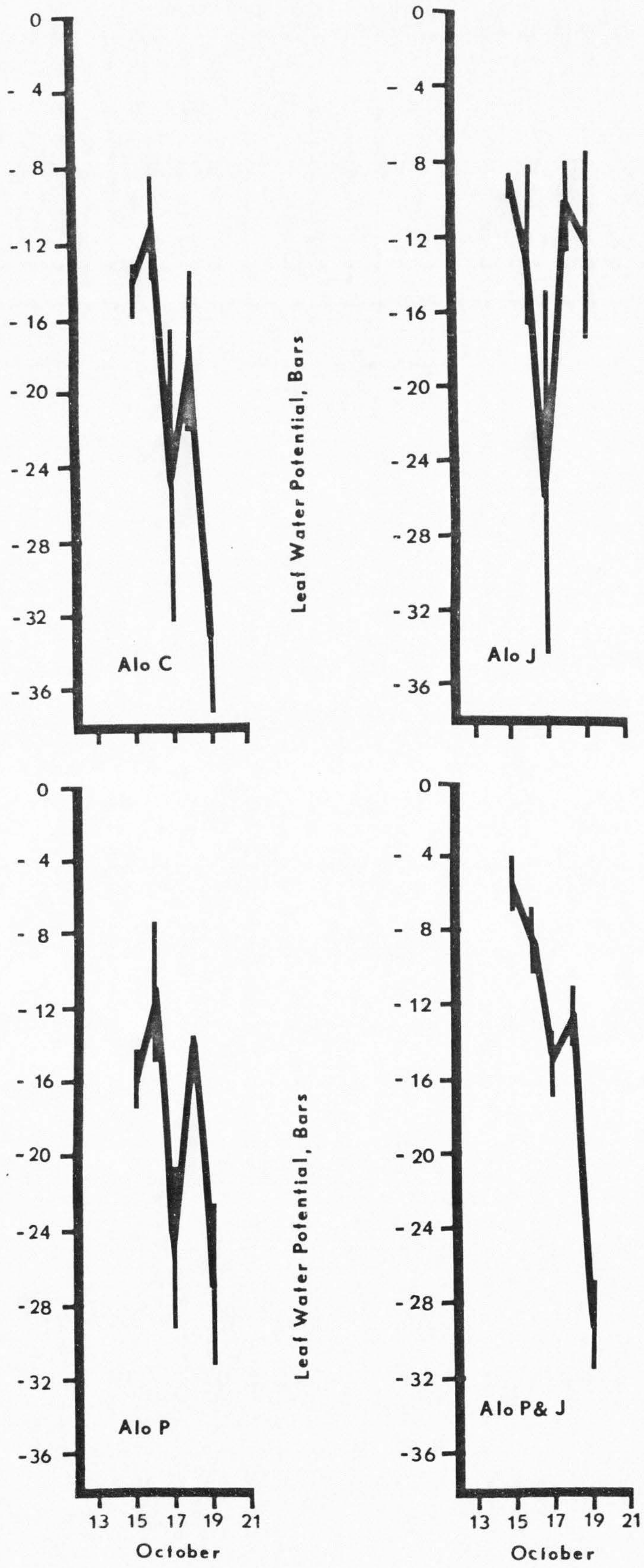
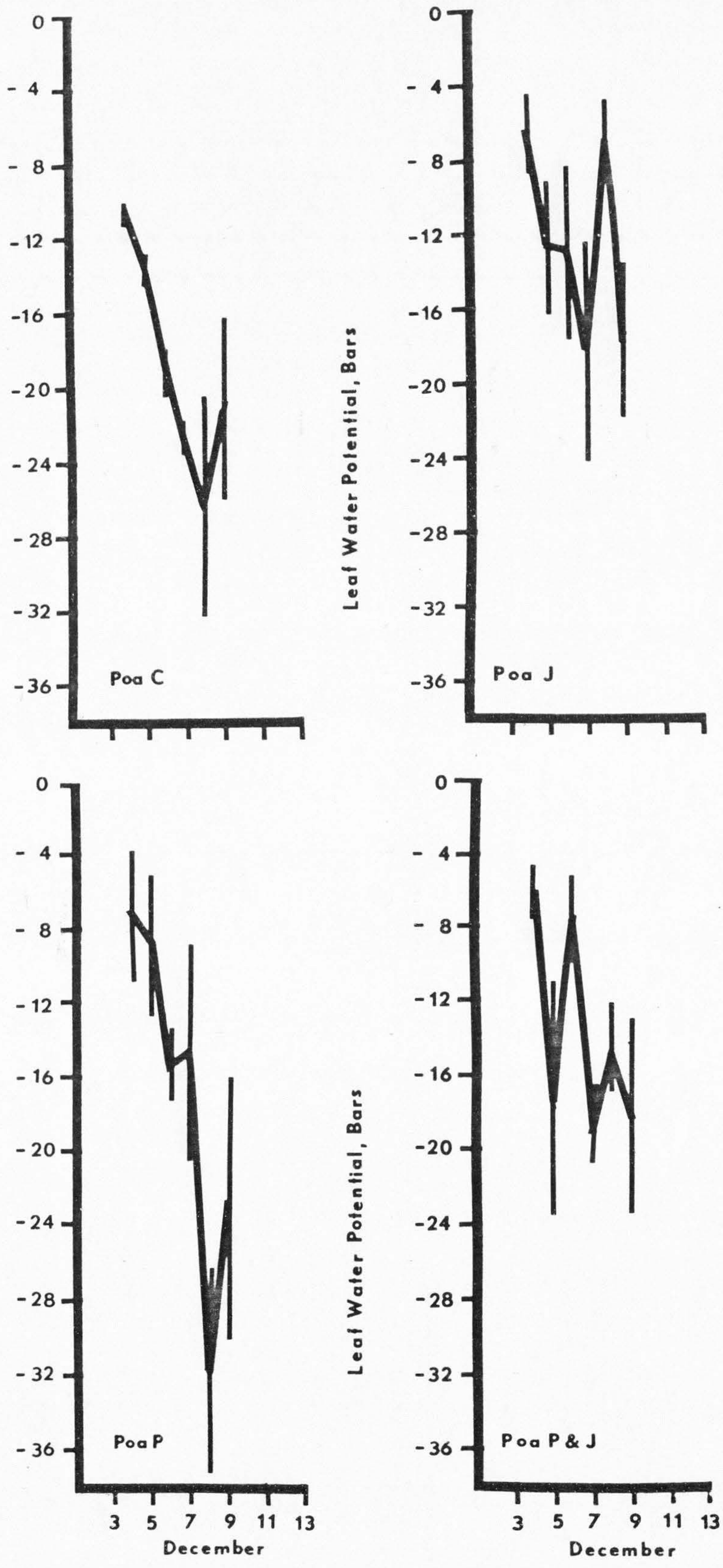

0
- 4
- 8
- 12
- 16
- 20
- 24
- 28
- 32
- 36
Alo C
Alo J
Alo P
Alo P& J
Leaf Water Potential, Bars
Leaf Water Potential, Bars
13 15 17 19 21
October
13 15 17 19 21
October

Figure 6. Mean daily growth chamber water potentials with associated standard errors for *Poa alpina* during the drying cycle. The number of replicates for each mean varies from 2 to 4. The following abbreviations are used: *Poa alpina* = Poa; Control = C; Peatmoss = P; Jute net = J; Peatmoss-plus-jute net = P + J.



Leaf Water Potential, Bars
0
- 4
- 8
- 12
- 16
- 20
- 24
- 28
- 32
- 36
Poa C
Poa J
Poa P
Poa P & J
3 5 7 9 11 13
December

ing cycle progresses. Leaf water potentials were generally drier in the growth chamber than in the field.

Leaf pressure potentials

Predicted leaf pressure potentials of 0 occurred at significantly different leaf water potentials. The regression line crosses leaf pressure potential of 0 at -23.3 bars leaf water potential for *Alopecurus* and at -14.8 bars for *Poa*, as seen in Figure 7.

When data from more than two days without water were examined, results were similar to field results. Results are presented in Table 5. Plants in the control group or with a peatmoss treatment had drier mean leaf pressure potentials than plants with the other treatments.

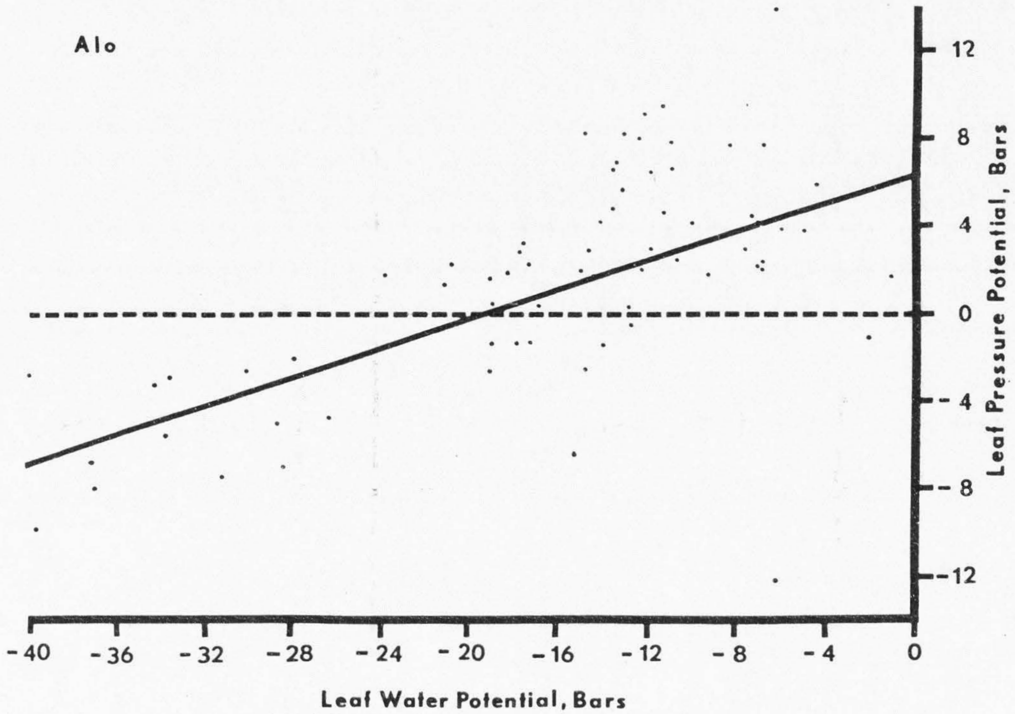
Seedling development, density and mortality

There were no significant differences in number of live plants, or number of dead plants on the subplots at the end of the drying cycle. There were significant differences between species in number of leaves per plant, and minimum and maximum heights of plants with the most common number of leaves, as seen in Table 6. *Alopecurus* plants had more leaves, and were taller than *Poa* plants.

Soil water potentials

There were also many soil water potentials which were more negative than the corresponding leaf water potentials in the growth chamber studies (Appendix A). Soil water potentials explained somewhat more of the variation in multiple regressions of leaf water potentials and climatic variables, but accounted for little of the variance, Table 7.

Figure 7. Growth chamber leaf water potential vs. apparent leaf pressure potential linear regressions for all treatments. The *Alopecurus pratensis* (Alo) regression line crosses apparent leaf pressure potential of 0 at -23.3 bars leaf water potential, $r^2 = .48$. The *Poa alpina* (Poa) regression line crosses apparent leaf pressure potential of 0 at -14.8 bars leaf water potential, $r^2 = .46$. The difference in leaf pressure potential of 0 is significant at the 1 percent level.


Alo
12
8
4
0
- 4
- 8
-12
Leaf Pressure Potential, Bars
- 40
- 36
- 32
- 28
- 24
- 20
- 16
- 12
- 8
- 4
0
Leaf Water Potential, Bars

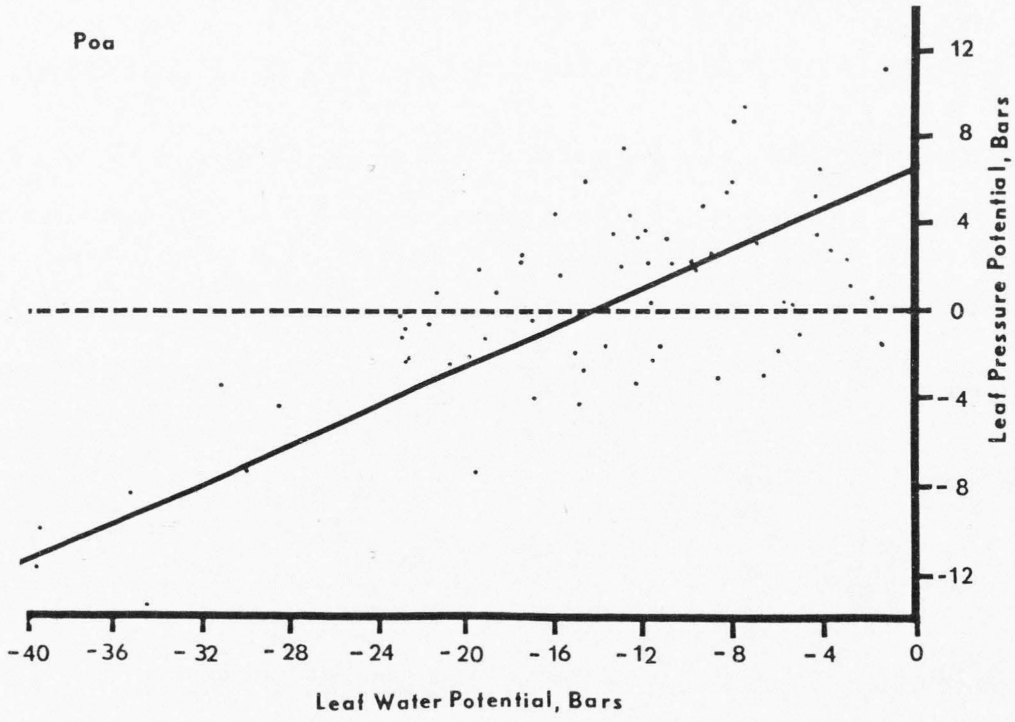

Poa
12
8
4
0
- 4
- 8
-12
Leaf Pressure Potential, Bars
-40
-36
- 32
- 28
- 24
- 20
- 16
- 12
- 8
- 4
0
Leaf Water Potential, Bars

Table 6. Means of seedling measurements taken in the growth chamber at the end of the drying cycle. Abbreviations are as follows: <u>Alopecurus pratensis</u> = Alo; <u>Poa alpina</u> = Poa; Control group = C; Peatmoss = P; Jute net = J; Peatmoss + jute net = P + J.

	Group	Number of live plants	Number of dead plants	Dead/ live + dead	Minimum plant height (cm)	Maximum plant height (cm)	Most common number of leaves
Species					**	**	
	Poa	9.3	3.8	0.29	1.2	2.0	1.9
	Alo	5.4	1.5	0.21	3.9	6.3	2.4
Treatments	C	6.1	3.8	0.38	1.8	2.9	1.9
	P	6.0	1.0	0.14	1.9	2.8	2.0
	J	7.6	2.8	0.27	3.3	5.4	2.4
	P + J	9.6	3.4	0.26	3.4	5.7	2.5
Species-treatment interactions	Poa C	8.5	5.5	0.39	1.3	2.1	2.0
	Poa P	5.8	1.3	0.18	1.1	1.3	2.0
	Poa J	9.5	3.5	0.27	1.1	2.0	1.8
	Poa P + J	13.3	4.8	0.26	1.6	2.9	2.0
	Alo C	3.8	1.3	0.25	2.6	3.8	1.8
	Alo P	6.3	0.8	0.11	2.8	4.3	2.0
	Alo J	5.8	2.0	0.26	5.5	8.8	3.0
	Alo P + J	6.0	2.0	0.25	5.3	8.5	3.0

**Significant at the 1 percent level

Table 7. Stepwise multiple regression of growth chamber data for each species-treatment combination. Leaf water potential (dependent variable) vs. relative humidity, air temperature, soil water potential and days since water (independent variables). The independent variable explaining the least amount of variation in leaf water potential is deleted first. The r^2 for the final independent variable in the equation is given.

Alopecurus pratensis

Control	Peatmoss	Jute net	Peatmoss-plus-jute net
Degrees of freedom = 14	Degrees of freedom = 15	Degrees of freedom = 10	Degrees of freedom = 14
Total r^2 = .35	Total r^2 = .21	Total r^2 = .42	Total r^2 = .81
Order deleted	Order deleted	Order deleted	Order deleted
air temperature	air temperature	air temperature	air temperature
relative humidity	relative humidity	days since water	relative humidity
soil water potential	soil water potential	relative humidity	soil water potential
days since water	days since water	soil water potential	days since water
r^2 = .3	r^2 = .17	r^2 = .15	r^2 = .73

Poa alpina

Control	Peatmoss	Jute net	Peatmoss-plus-jute net
Degrees of freedom = 18	Degrees of freedom = 18	Degrees of freedom = 16	Degrees of freedom = 18
Total r^2 = .61	Total r^2 = .45	Total r^2 = .27	Total r^2 = .35
Order deleted	Order deleted	Order deleted	Order deleted
days since water	soil water potential	relative humidity	days since water
air temperature	relative humidity	soil water potential	soil water potential
relative humidity	air temperature	days since water	air temperature
soil water potential	days since water	air temperature	relative humidity
r^2 = .37	r^2 = .39	r^2 = .1	r^2 = .08

DISCUSSION

Analyses of treatment effects on leaf water potentials for the field season do not directly indicate plant responses to water stress, because of the amount of precipitation received. The 1976 field season was wetter than the previous year. Approximately 9.7 cm of precipitation were recorded from August 1 to the middle of September in 1976, as compared to 1.1 cm of precipitation in the same period in 1975. Spring snowmelt in 1976 occurred approximately two weeks in advance of the 1972-1975 field seasons. However, despite the early snowmelt, frequent rainfall maintained relatively high soil water potentials. In a year with less precipitation soil water potentials would probably be lower. Mean leaf water potentials do give a general indication of the effects of the treatments. The lower mean leaf water potential for the *Alopecurus* control pots in the growth chamber might be due to increased water use due to larger plant size. Both peatmoss and jute net appear to maintain spoil water potentials at higher levels than untreated spoils. Jute net seems to be more effective than peatmoss in reducing water stress.

Jute net also seems to be more effective than peatmoss in reducing the levels of plant water stress for more than two days without water. This could be due to several microclimatic changes brought about by a jute net surface mulch.

In general, surface mulches lessen rainfall intensity and allow more water to penetrate into the soil (Rickert, 1973). The jute net is a rough barrier to air flow, and creates a larger boundary of still air which reduces the rate of evaporation from the soil (Hanks, 1967), and can increase the air temperature of the seedling environment. The jute itself absorbs water, and evaporation from the fiber provides a higher relative humidity for the seedlings. These factors decrease the daily depth of soil water loss (Hanks and Woodruff, 1958).

The variability in the apparent leaf pressure potential vs. leaf water potential data may be due to a high degree of variability within the seedling population, or due to problems with the technique. The large amount of variation in the field data might be attributable to physiological differences in the seedling leaves as they aged (Woolhouse, 1967). However, the growth chamber data also show a high degree of variability when leaves were approximately the same age. Brown (1974), Johnson (1975), and Johnson and Brown (1977) also found a high degree of variability in apparent leaf pressure potential vs. leaf water potential data.

The existence of negative turgor pressures is being debated. It is possible that killing the plant tissue and rupturing the plant membranes alters the magnitude of the components of leaf water potential (Tyree, 1976). Other researchers, for example Noy-Meir and Ginzburg (1967) and Warren Wilson (1967), find no theoretical inconsistency in negative leaf pressure potentials since their model linearly relates leaf pressure potential to the amount of water in the leaf.

Although there were significant differences in predicted leaf pressure potentials of 0 for Alopecurus and Poa, the discussion above makes conclusions about differences and relative plant drought resistance highly tentative.

Many of the points with leaf water potential and apparent leaf pressure potential close to 0 were obtained towards the end of a drying cycle. One possible explanation for these points is that seedlings had closed stomates and were respiring the small amount of carbohydrates which were produced. The reduction in solute concentration and production of CO_2 and water by respiration may have caused the leaf water potential to become less negative.

The variability in the data collected may be due in part to the genetic variation within the seedling population. The genetic variability is likely to be high while selective forces are acting upon unadapted organisms in the seedling population (Sarukhan and Harper, 1973; Canfield, 1957). Another source of variability in the data could be plant response to microsite differences (Harper et al., 1965).

In the field there was a high degree of variability in numbers of plants within a species-treatment combination (Appendix B). Some of this variability could be explained by small differences in technique during plot establishment. The spoils are also quite variable, and the presence of a higher proportion of acid-producing pyrite could limit seedling emergence. Another factor which could explain some variability is the wind. The wind generally blows from the west. Poa and Alopecurus with peatmoss in Block 3, had small number of plants. The small number of plants on these plots may be due to the location in the west corner of the site. The relatively small number of plants on these two plots experienced the highest mortality rates. The higher proportion of dead Alopecurus plants might be caused by a lower toxic threshold for Al, Zn, Cu, or Fe, or perhaps the competition between plants is greater since Alopecurus plants were larger.

Since Poa is native to the study area, and is probably better adapted to the climatic conditions, it might be predicted to do better than a species adapted to other climatic conditions. However, Alopecurus may be better adapted, in the seedling stage, to the conditions on the acid mine spoils. Alopecurus has been used successfully in revegetation efforts at high elevations in the West (U. S. Forest Service, 1966; Brown et al., 1976; Hendzel, 1976).

The number of leaves and heights of plants seems to be characteristic of species, and treatment had little effect. These are probably genetically determined traits.

The plants grown in the greenhouse and growth chamber experienced a very different environment than plants in the field. Both air temperature and soil temperature were higher than in the field and plants grew more quickly and were taller. Larger plant size and more favorable growing conditions may help to explain why there were no significant differences in number of live plants or number of dead plants. The ratio of dead plants to live plus dead plants was much higher in the growth chamber than in the field. This indicates that plants experienced more stress in the growth chamber.

The driving force for movement of water in the soil-plant-atmosphere continuum is gradients in the free energy of water (Hsiao, 1973). In order for soil water to move into plants, the plant water must have a lower chemical potential than the soil water (Slatyer, 1967; Kramer, 1969). Unless soil water becomes limiting, soil water potentials shouls be less negative than corresponding leaf water potentials (Slatyer, 1967; Kramer, 1969). Several of the soil water potentials obtained in these studies are questionable because they are more negative than leaf water potentials, when plants appeared to be healthy. One problem in obtaining reliable estimates of soil water potential is determining the zone of root water absorption. Growth chamber estimates of soil water potential were probably in error because the root systems extended below the level where the soil sample was taken.

Other possible errors in estimating spoil water potentials include spoil sampling techniques. Before spoils were placed in equilibration chambers, they had a short exposure to air which had a much lower concentration of water. If spoil water was lost to the atmosphere because of water concentration gradients, spoil water potential readings would be more negative. For the growth chamber studies, the spoils were sieved to 2 mm. The clay loam texture of particles less than 2 mm caused the spoils to shrink and pull away from the sides of the pots as the spoils dried. The subsurface spoils became exposed to the air. The spoils often pulled away from the walls below the depth that spoil cores were taken. Also, the holes left by the corer allowed air to penetrate into the spoil mass. The tip of each core was removed before a sample was placed in the equilibration chamber, but there may have been some dry spoil included in the sample. It is apparent that spoil water potentials do not correlate well with leaf water potentials. This could be caused by inaccurate instruments, or techniques of obtaining samples.

Tensiometer measurements indicated that spoil water was available at a depth of 7.5 cm. Plant roots may not have reached this source of water. Low spoil temperatures, acidity, and the lack of nutrients available to plants could limit root growth. Root systems of mature grass plants growing on the mine rarely exceed 10 cm in depth.

CONCLUSIONS

1. Seedling water stress was reduced by the spoil treatments. Treatments of jute net or peatmoss plus jute net were most effective in reducing plant water stress.
2. Apparent leaf pressure potential of 0 occurred at more negative leaf water potentials for *Alopecurus pratensis* than for *Poa alpina.*
3. Treatments of jute net, or peatmoss plus jute net decreased rates of seedling mortality in the field, but not in growth chamber studies.

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APPENDICES

Appendix A. Leaf water potentials, osmotic plus matric potentials, apparent pressure potentials and soil water potentials for *Alopecurus pratensis* and *Poa alpina* all treatments, field and growth chamber studies.

Alopecurus pratensis Control Plots

Field season leaf water potentials (ψ_ℓ), Osmotic plus matric potentials ($\psi_\pi+\psi_\tau$), apparent pressure potentials (ψ_ρ), and soil water potentials (ψ_s). All measurements are in bars.

	Block 1			Block 2				Block 3				Block 4		
Date	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ
8-09	-18.5	-19.3	+ 0.8	-20.0	-22.6	+ 2.6	- 5.8	-17.5	-20.2	+ 2.7		-11.6	-17.5	+ 5.9
8-10	-12.3	-13.0	+ 0.7	-24.0	-29.2	+ 5.2	- 8.9	-11.6	-16.6	+ 5.0		-17.5	-23.0	+ 5.5
8-11	-20.8	-3.4	-17.4	-14.5	-23.4	+ 8.9	- 9.6	-30.0	- 7.5	-22.5		-10.1	-17.5	+ 7.4
8-12	-19.8			-13.9	-15.7	+ 1.8	- 7.4	- 2.4	-10.0	+ 7.6	- 6.0	-16.6	-23.6	+ 7.0
8-13	-10.0	-12.4	+ 2.4	-22.2	-20.2	- 2.0	- 7.6	-17.4	-17.6	+ 0.2		-11.3	-20.3	+ 9.0
8-14	-25.2	-25.1	- 0.1	-18.0	-16.8	- 1.2	- 4.9	-13.3	-16.9	+ 3.6	- 8.0			
8-15				-27.0	-28.3	+ 1.3	-14.2	-11.2	-12.2	+ 1.0		- 7.0	-18.7	+11.7
8-16	-12.0	-19.4	+ 7.4	-15.3	-21.3	+ 6.0	- 4.0	-16.0	-22.7	+ 6.7	- 2.8	-15.1	-19.0	+ 3.9
8-17	-15.5	-19.3	+ 3.8	-16.6	-23.7	+ 7.1	- 5.0	-16.6	-18.8	+ 2.2	- 5.5	-15.6	-22.1	+ 6.5
8-18	-14.2	-15.6	+ 1.4				- 2.5				- 2.9	- 2.8	- 4.0	+ 1.2
8-19	- 2.9	-15.8	+12.9				- 3.0	- 2.4	-12.8	+10.4	- 4.4	-13.7	-23.4	+ 9.7
8-20	-20.9	-25.3	+ 4.4	-16.3	-24.6	+ 8.3								
8-21				-14.0	-18.7	+ 4.7	- 6.6	-15.1	-19.3	+ 4.2	- 3.8	-13.4	-22.3	+ 8.9
8-22	-17.0	-21.0	+ 4.0	- 7.0	- 7.3	+ 0.3	-15.1	-12.8	-18.5	+ 5.7		-21.0	-18.3	- 2.7
8-23														
8-24	-12.0	-20.8	+ 8.8	- 8.2	-18.6	+10.4	- 7.8					-10.9	-18.8	+ 7.9
8-25	-12.2	-10.2	- 2.0	- 9.0	- 8.5	- 0.5	- 4.0	-11.3	-14.0	+ 2.7	- 5.0	-18.4	-23.1	+ 4.7
8-26	-21.0	-22.1	+ 1.1				- 8.0	-12.8	- 9.6	- 3.2	- 5.1	- 7.5	-16.8	+ 9.3
8-27														
8-28	-20.0	-24.6	+ 4.6	-16.3	-21.4	+ 5.1	- 7.0	-17.0	-22.1	+ 5.1	- 3.9	-11.0	-16.0	+ 5.0
8-29	-12.0	-14.6	+ 2.6	-20.0	-18.3	- 1.7	- 5.0	- 5.5	- 6.4	+ 0.9	- 6.1	- 3.4	-11.3	+ 7.9
8-30														
8-31				- 7.8			- 6.6	- 8.9	- 9.2	+ 0.3	- 6.1	-22.0	-18.9	- 3.1
9-01	- 4.0	-12.2	+ 8.2	-19.0	-18.9	- 0.1	- 9.9	-15.5	-17.5	+ 2.0	- 8.2	-14.7	-18.6	+ 3.9
9-02	- 9.0	- 9.8	+ 0.8	-20.3	-18.2	- 1.9	- 7.7	-31.5	- 8.5	-23.0	- 7.1	-18.0	-21.0	+ 3.0
9-03	- 9.2	- 9.2	0.0				-11.0	-20.6	-21.1	+ 0.5	-13.0	-29.5	-28.8	- 0.7
9-04				-42.0	-15.8	-26.2	- 8.3	-25.9	-13.3	- 2.6	- 5.9	-28.7	-28.9	+ 0.2
9-05							-10.7				- 4.1			
9-06	-21.0	-23.0	+ 2.0	-30.0	-24.0	- 6.0	-9.0	-20.5	-14.0	- 6.5	- 6.0	-15.8	-17.0	+ 1.2

Alopecurus pratensis Peatmoss Plots

Field season leaf water potentials (ψ_ℓ), osmotic plus matric potentials ($\psi_\pi+\psi_\tau$), apparent pressure potentials (ψ_ρ), and soil water potentials (ψ_s). All measurements are in bars.

	Block 1				Block 2				Block 3			Block 4		
Date	ψ_ρ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s	ψ_ℓ	ψ_π ψ_τ	ψ_ρ	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_ρ	ψ_π ψ_τ	ψ_ρ
8-09	-17.1	-20.7	+3.6	-2.0	-12.2	-21.5	+9.3	-6.2	-13.3	-17.6	+4.3	-4.3	-6.0	+1.7
8-10	-23.0	-24.0	+1.0	-1.0	-8.9	-19.0	+11.1	-2.6	-18.3	-20.8	+2.5	-2.4	-2.4	0.0
8-11	-8.5	-7.5	-1.0	-6.6	-20.0	-20.6	+0.6	-9.0	-14.5	-18.6	+4.1	-17.7	-24.9	+7.2
8-12	-12.2	-12.9	+0.7	-9.7	-12.6	-19.0	+6.4	-7.1				-19.0	-23.9	+4.9
8-13			-	-5.0	-8.6	-1.0	-7.6		-26.0	-22.4	-3.6	-12.0	-19.0	+7.0
8-14				-5.0	-17.5	-22.7	+5.2	-10.7	-30.6			-15.6	-15.9	+0.3
8-15	-12.3	-19.2	+6.9	-5.6	-21.9	-21.4	-0.5	-13.3	-22.2	-11.2	-11.0	-14.0	-20.5	+6.5
8-16	-11.4	-15.6	+4.2	-3.4	-10.0	-23.3	+13.3	-4.5	-14.9	-12.6	-2.3	-11.7	-15.3	+3.6
8-17	-26.5	-25.2	-1.3	-5.3	-21.2			-8.3				-12.6	-11.0	-1.6
8-18	-12.7	-10.8	-1.9	-2.9	-6.9	-4.9	-2.0	-4.8	-10.7	-15.0	+4.3	-4.8	-15.0	+10.2
8-19	-11.0	-12.0	+1.0	-2.8	-8.1	-20.7	+12.6	-5.5	-13.9	-19.5	+5.6	-10.0	-19.6	+9.6
8-20	-28.2	-27.7	-0.5		-13.6	-13.2	-0.4		-9.7	-13.5	+3.8	-16.7	-19.9	+3.2
8-21	-15.8	-21.0	+5.2	-5.3	-9.0	-18.2	+9.2	-6.4				-4.3	-11.6	+7.3
8-22	-10.0	-13.7	+3.7	-8.9	-16.4	-20.0	+3.6	-9.4	-23.3	-21.0	-2.3	-16.4	-18.0	+1.6
8-23														
8-24	-8.9	-14.3	+5.4	-4.0	-13.5	-20.0	+6.5	-6.1				-9.0	-6.7	-2.3
8-25	-12.3	-14.3	+2.0	-3.8	-15.3	-19.3	+4.0	-8.3	-9.9	-11.1	+1.2	-13.9	-21.0	+7.1
8-26	-8.1	-13.7	+5.6	-4.8	-12.0	-22.7	+10.7	-7.9	-18.0	-20.0	+2.0			
8-27														
8-28	-16.0	-22.6	+6.6	-4.0	-9.7	-20.4	+10.7	-9.0				-11.0	-15.2	+4.2
8-29	-22.7	-11.9	-10.8	-13.3	-11.3	-18.0	+6.7	-8.1				-14.8	-17.3	+2.5
8-30														
8-31	-3.0	-17.0	+14.0	-5.1	-8.4	-8.2	-0.2	-10.9				-5.5	-10.5	+5.0
9-01	-17.9	-20.2	+2.3	-8.7	-8.0	-1.2	-6.8	-15.4				-7.0	-11.8	+4.8
9-02	-6.0	-8.5	+2.5	-5.9	-17.8	-18.3	+0.5	-9.0				-23.7	-18.0	-5.7
9-03	-20.0	-16.1	-3.9	-9.5	-4.5	-18.6	+14.1	-11.0				-11.0	-18.0	+7.0
9-04	-5.0	-3.0	-2.0	-5.7	-17.5	-14.7	-2.8	-9.7				-9.4	-12.0	+2.6
9-05				-10.6				-13.5						
9-06	-17.1	-17.8	+0.7	-12.2				-16.0				-22.0	-11.0	-11.0

Alopecurus pratensis Jute Net Plots

Field season leaf water potentials (ψ_ℓ), osmotic plus matric potentials ($\psi_\pi+\psi_\tau$), apparent pressure potentials (ψ_p), and soil water potentials (ψ_s). All measurements are in bars.

	Block 1				Block 2				Block 3			Block 4		
Date	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p
8-09	-14.6	-20.0	+5.4	-2.6	-9.2	-14.2	+5.0	-9.0	-10.0	-19.5	+9.5	-8.7	-15.4	+6.7
8-10	-11.5			-1.3	-3.2	-5.2	+2.0	-7.4	-14.1			-10.3	-15.7	+5.4
8-11	-2.0	-4.4	+2.4	-6.0	-13.4	-15.5	+2.1	-6.6	-14.2	-16.4	+2.2	-0.7	-1.3	+0.6
8-12				-5.2	-10.5	-15.8	+5.3	-9.5	-15.0	-18.5	+3.5	-1.6	-3.8	+2.2
8-13	-16.1	-16.6	+0.5	-5.9	-15.0	-19.0	+4.0	-6.7	-18.9	-21.4	+2.5	-10.9	-13.2	+2.3
8-14	-7.3	-17.3	+10.0	-8.4	-25.4	-5.4	-20.0	-12.0	-11.2	-11.2	0.0	-9.5	-14.4	+4.9
8-15	-9.6	-15.0	+5.4	-5.1	-18.5	-14.0	-4.5	-9.4	-11.7	-21.1	+9.4	-20.0	-13.0	-7.0
8-16	-7.2	-12.3	+5.1	-3.9	-7.9	-10.5	+2.6	-2.3	-8.5	-9.2	+0.7	-16.0	-20.5	+4.5
8-17	-8.4	-18.3	+9.9	-7.1	-16.0			-2.0	-10.8	-14.7	+3.9	-12.0	-14.0	+2.0
8-18	-8.5	-15.1	+6.6	-3.3	-9.4	-14.1	+4.7	-3.8	-6.7	-15.7	+9.0	-7.8	-16.0	+8.2
8-19	-6.8	-10.2	+3.4	-4.2	-8.0	-17.3	+9.3	-2.0	-7.8	-18.7	+10.9	-16.2	-22.1	+5.9
8-20	-13.8	-7.2	-6.6		-3.8	-11.5	+7.7		-4.4	-10.2	+5.8	-12.1	-15.0	+2.9
8-21	-10.4	-16.8	+6.4	-12.4	-14.9	-20.0	+5.1	-5.7	-7.2	-11.7	+4.5	-12.0	-25.9	+3.9
8-22	-14.3	-18.4	+4.1	-7.9	-11.0	-13.8	+2.8		-15.5	-19.9	+4.4	-16.0	-17.8	+1.8
8-23														
8-24	-7.5	-12.0	+4.5	-4.9	-1.0	-5.7	+4.7	-1.8	-10.4	-17.6	+7.2	-6.0	-12.8	+1.8
8-25	-10.3	-14.3	+4.0	-4.6	-9.4	-17.0	+7.6		-6.2	-14.0	+7.8	-10.0	-16.0	+6.0
8-26	-11.6	-11.6	0.0	-4.3	-6.5	-8.1	+1.6	-7.0	-10.3	-18.6	+8.3	-8.7	-15.0	+6.3
8-27														
8-28	-9.5	-13.7	+4.2	-5.6	-19.1				-8.2	-11.7	+3.5	-4.7		
8-29	-20.0	-18.7	-1.3	-6.0	-16.2	-19.8	+3.6	-9.0	-7.9	-10.0	+2.1	-11.6	-16.4	+4.8
8-30														
8-31	-21.0	-14.3	-6.7	-13.0	-8.5	-14.0	+5.5	-8.2	-8.0	-19.7	+11.7	-8.5	-9.6	+1.1
9-01	-9.4	-16.7	+7.3		-13.4	-18.6	+5.2	-8.9	-10.0	-16.0	+6.0	-14.0	-19.6	+5.6
9-02	-16.0	-16.7	+0.7	-7.2	-11.0	-19.4	+8.4	-11.0	-34.0	-29.9	-4.1	-14.5		
9-03	-26.5	-23.6	-2.9	-10.2	-12.4	-10.0	-2.4	-8.9	-23.0	-17.4	-5.6	-13.0	-18.0	+5.0
9-04	-5.5	-12.7	+7.2	-7.2	-23.8	-16.9	-6.9	-22.9	-16.0	-17.6	+1.6	-9.6	-7.0	-2.6
9-05				-14.4				-13.0						
9-06	-18.6	-20.9	+2.3	-25.0	-38.7	-16.9	-21.8	-9.0	-27.4	-11.9	-15.5	-23.6	-20.5	-3.1

Alopecurus pratensis Peatmoss-plus-Jute Net Plots

Field season leaf water potentials (ψ_ℓ), osmotic plus matric potentials ($\psi_\pi+\psi_\tau$), apparent pressure potentials (ψ_ρ), and soil water potentials (ψ_s). All measurements are in bars.

	Block 1			Block 2				Block 3				Block 4		
Date	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ
8-09	-12.4	-20.0	+ 7.6	-15.0	-19.0	+ 4.0	- 4.4	-14.0	-21.0	+ 7.0	- 4.0	- 7.9	-18.7	+10.8
8-10	- 5.0	-10.3	+ 5.3	-16.5	-17.7	+ 1.2	- 6.0	- 6.2	-19.0	+12.8		- 9.5	-17.3	+ 7.8
8-11	- 7.9	-15.0	+ 7.1	-14.3	-17.5	+ 3.2	- 5.0				- 6.1			
8-12	- 2.0	- 4.1	+ 2.1	-10.8	- 6.3	- 4.5		- 9.9	-18.6	+ 8.7		- 3.3	-20.6	+17.3
8-13				- 8.7	-16.8	+ 8.1		-13.1	-20.0	+ 6.9	-10.2	- 7.0	- 8.1	+ 1.1
8-14	-17.9	-21.4	+ 3.5	-15.3	-17.0	+ 1.7	- 2.9	-21.2	-22.2	+ 1.0		-16.4	-17.4	+ 1.0
8-15	-11.0	-19.1	+ 8.1	-14.1	-15.3	+ 1.2		- 8.1	-13.6	+ 5.5	-11.0	-11.8	-12.5	+ 0.7
8-16				-12.4	-12.0	- 0.4	- 3.2	-19.0	-24.1	+ 5.1	- 6.0	-14.0	- 3.7	-10.3
8-17				-11.6	-14.0	+ 2.4	- 6.2	- 7.2	-12.4	+ 5.2	- 6.0	-11.8	-17.9	+ 6.1
8-18	- 3.8	- 6.5	+ 2.7	- 3.8	-11.1	+ 7.3	- 1.2	- 9.6	-15.9	+ 6.3		- 4.5	- 8.1	+ 3.6
8-19				- 7.7	-15.9	+ 8.2	- 4.7	- 2.4	-20.8	+18.4	- 5.4	-12.3	-19.0	+ 6.7
8-20	-15.4	-15.4	0.0	- 1.7	- 4.2	+ 2.5		- 2.1	- 2.1	0.0		-14.5	-15.8	+ 1.3
8-21	- 9.7	-15.8	+ 6.1	-10.1	-14.7	+ 4.6	- 6.9	- 7.3	-16.8	+ 9.5	- 3.8	-18.7	- 4.0	-14.7
8-22	- 6.0	-14.0	+ 8.0	-12.3	-17.4	+ 5.1	-11.0	- 7.6	-13.6	+ 6.0	- 8.6	-17.5	- 9.2	- 8.3
8-23														
8-24	- 1.0	- 8.0	+ 7.0	- 2.0	- 4.2	+ 2.2	- 4.7	- 2.4	- 10.3	+ 7.9		-10.0	-19.0	+ 9.0
8-25	- 8.1	-13.0	+ 4.9	- 7.9	- 2.4	- 5.5	- 5.0	-13.3	- 8.8	- 4.5	- 6.1	-14.6	-16.3	+ 1.7
8-26	- 2.0	-10.2	+ 8.2	- 4.2	- 9.0	+ 4.8	- 3.9	- 7.2	-14.6	+ 7.4	- 4.9	- 9.2	-12.9	+ 3.7
8-27														
8-28	- 6.1	-10.1	+ 4.0	- 8.6	-16.8	+ 8.2	- 5.4	- 5.1	-12.2	+ 7.1	- 5.2	- 3.5	- 8.4	+ 4.9
8-29	- 3.8	- 6.0	+ 2.2	-13.7	-13.9	+ 0.2		-15.0	-17.5	+ 2.5	- 4.7	- 4.7	-10.8	+ 6.1
8-30														
8-31	-23.6	-20.2	- 3.4	-11.4	-18.1	+ 6.7		- 2.0	-16.0	+14.0	- 7.1	-15.0	- 9.6	- 5.4
9-01	-23.6	-20.2	- 3.4					- 6.6	-18.4	+11.8	-20.1	-13.0	- 9.3	- 3.7
9-02	-16.6	-11.8	- 4.8	-12.0	-14.5	+ 2.5		-12.8	-15.3	+ 2.5	- 7.2	-25.3	-16.0	- 9.3
9-03	-23.7	-20.0	- 3.7	- 5.8	-11.9	+ 6.1		-17.4	-13.4	- 4.0	-13.7	- 5.9	-10.5	+ 4.6
9-04	-21.9	-20.4	- 1.5	-16.5	-14.9	- 1.6	-14.0					- 9.3	- 9.0	+ 0.3
9-05							- 5.4				-18.0			
9-06	-30.0	-11.6	-18.4	-21.9	-19.5	- 2.4	- 8.2	- 8.2	- 9.6	+ 1.4		-23.0	-20.3	- 2.7

Poa alpina Control Plots

Field season leaf water potentials (ψ_ℓ), osmotic plus matric potentials ($\psi_\pi + \psi_\tau$), apparent pressure potentials (ψ_ρ), and soil water potentials (ψ_s). All measurements are in bars.

	Block 1			Block 2				Block 3				Block4		
Date	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s	$\psi\psi_\ell$	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ
8-09											- 6.9			
8-10											-10.3			
8-11											- 8.6			
8-12							- 6.7				- 8.9			
8-13							-10.5					-16.7	-19.0	+ 2.3
8-14							-12.0				- 4.5			
8-15							- 8.7							
8-16							- 5.0							
8-17							- 5.3							
8-18							- 3.2				- 4.0			
8-19							- 4.9							
8-20														
8-21							- 8.4				- 4.8			
8-22				-23.3	-22.9	- 0.4	-15.2					-15.7		
8-23														
8-24							- 6.0				- 3.0	- 6.9	-15.3	+ 8.4
8-25				-19.4	-13.6	- 5.8	- 6.1				- 3.5	-18.4	-14.0	- 4.4
8-26	-12.9	-11.2	- 1.7	- 8.8	-13.7	+ 4.9	- 6.2				- 6.0	- 6.0	-15.9	+ 9.9
8-27														
8-28	-20.4	-24.4	+ 4.2	- 7.0	- 8.0	+ 1.0	- 9.6				- 5.3	-15.5	-20.6	+ 5.1
8-29	-18.1	-16.3	- 1.8	-25.1			- 5.8				- 5.3	-22.5	-11.5	-11.0
8-31	- 4.4	-20.5	+16.1	-17.8	-17.7	- 0.1	-28.4				- 5.3	-23.9	-22.0	- 1.9
9-01	-22.4	-17.6	- 4.8	-23.0	- 1.9	-21.1	- 9.6				- 3.5	-13.9	-21.9	+ 8.0
9-02	-23.3	-21.4	- 1.0	-20.4	-18.0	- 2.4	-12.3				- 9.7	-33.0	-26.6	- 6.4
9-03	-26.0	-24.2	- 1.8	-13.6	-21.7	+ 8.1	-23.0				- 8.1	-26.3	-26.3	0.0
9-04	-29.4	-23.5	- 5.9	-14.1	-12.8	- 1.3	-26.8				-11.2	-29.5	-24.8	- 4.7
9-05							-16.0				-10.5			
9-06	-31.4	-22.0	- 9.4	-24.0	-30.3	+ 6.3	- 8.2					-34.0	-26.9	- 7.1

Poa alpina Peatmoss Plots

Field season leaf water potentials (ψ_ℓ), osmotic plus matric potentials ($\psi_\pi+\psi_\tau$), apparent pressure potentials (ψ_ρ), and soil water potentials (ψ_s). All measurements are in bars.

	Block 1				Block 2			Block 3			Block 4			
Date	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s
8-09				- 2.9										- 5.9
8-10				- 2.9										-10.8
8-11	-10.5	-13.2	+ 2.7	- 4.5	-13.0	-17.3	+ 4.3							- 6.7
8-12	-15.9	-15.9	0.0											-11.7
8-13				-10.9										- 5.5
8-14	-19.4	-21.0	+ 1.6		-20.0	-22.6	+ 2.6							
8-15				- 3.0										- 7.2
8-16	-11.4	-18.3	+ 6.9	- 3.1							-13.5	-16.4	+ 2.9	- 2.2
8-17	-18.7	-21.2	+ 2.5											- 4.1
8-18	-13.4	-13.7	+ 0.3	- 1.5	- 6.4	-12.2	+ 5.8							- 3.6
8-19	-11.0	-20.9	+ 9.9	- 3.2										- 3.2
8-20	-17.3	-22.5	+ 5.2											
8-21	-16.0	-18.3	+ 2.3	- 4.0	-16.0	- 9.0	- 7.0							- 3.2
8-22	-20.0	-20.4	+ 0.4	- 6.4	-24.0	-23.0	- 1.0							- 7.7
8-23														
8-24	- 8.0	-14.5	+ 6.5	- 3.0							- 6.1	-12.8	+ 6.7	- 1.9
8-25	-17.5	-23.0	+ 5.5	- 4.3	-19.6	-21.2	+ 1.6				- 7.9	- 9.0	+ 1.1	- 5.6
8-26	-10.6	-17.3	+ 6.7	- 2.0	-11.3	-16.3	+ 5.0				-19.7	-14.0	- 5.7	-12.0
8-27														
8-28	- 9.3	-13.2	+ 3.9	- 4.9	-17.1	-18.5	+ 1.4							
8-29	-22.7	-19.0	- 3.7	- 5.6	- 6.6	- 5.3	- 1.3							
8-30														
8-31	- 4.0	-20.3	+16.3	-16.4	- 2.3	-14.1								- 4.8
9-01	-10.2	- 9.9	- 0.3	- 4.9	-24.5	-24.9	- 0.4							
9-02	- 7.2	- 9.3	+ 2.1	- 8.1	-21.6	-16.8	- 4.8							- 6.9
9-03	-22.4	-21.0	- 1.4		-17.0	-17.5	+ 0.5							
9-04	-24.2	-19.4	- 4.8		-26.6	-23.7	- 2.9							- 8.0
9-05				-20.7										-21.9
9-06	-27.0	- 2.1	-24.9	-21.4	-18.9	- 1.4	-17.5							-20.3

Poa alpina Jute Net Plots

Field season leaf water potentials (ψ_ℓ), osmotic plus matric potentials ($\psi_\pi+\psi_\tau$), apparent pressure potentials (ψ_ρ), and soil water potentials (ψ_s). All measurements are in bars.

	Block 1				Block 2			Block 3			Block 4			
Date	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_ρ	ψ_s
8-09	- 9.1	-12.8	+ 3.7	- 3.0	-16.3	-20.0	+ 3.7	-10.6	-16.9	+ 6.3	- 6.6	- 8.7	+ 2.1	- 3.0
8-10	-13.3	-17.0	+ 3.7	- 4.0	-10.6	-15.8	+ 5.2	-10.3	-17.0	+ 6.7	- 9.6	-16.0	+ 6.4	
8-11	-14.7	-17.0	+ 2.3	- 4.0	-16.0	-20.0	+ 4.0	-14.7	-12.3	- 2.4	-18.8	-16.7	- 2.1	- 4.0
8-12				- 1.7	- 6.0	-10.2	+ 4.2	- 6.4	-14.0	+ 7.6				- 4.5
8-13	-15.2	-18.0	+ 2.8		-16.4	-19.0	+ 2.6	-13.8	-18.6	+ 4.8				- 5.0
8-14	- 6.0	- 6.8	+ 0.8	- 2.1	0.0	- 1.0	+ 1.0							- 7.4
8-15	-14.9	- 8.3	- 6.6	- 8.7	-15.0	-20.0	+ 5.0	-10.4	-16.0	+ 5.6	- 7.2			- 6.5
8-16	-11.7	-18.3	+ 6.6	- 3.3	- 9.6			- 9.0	-15.5	+ 6.5	- 8.3	-15.0	+ 6.7	- 2.5
8-17	-13.8			- 4.0	-17.1	-19.7	+ 2.6	-10.8	- 9.6	- 1.2	-10.0	-16.5	+ 6.5	- 7.9
8-18	- 8.5	-15.1	+ 6.6	- 3.0	- 7.2	-14.8	+ 7.6	- 7.5	-17.0	+ 9.5	- 8.0	-12.9	+ 4.9	- 4.0
8-19	- 5.7	-16.3	+10.6	- 5.2	-10.9	-17.0	+ 6.1	- 6.3	-11.7	+ 5.4	- 7.0	-15.0	+ 8.0	- 4.9
8-20	-17.7	-19.0	+ 1.3		-12.4	-16.3	+ 3.9	- 9.2	-17.4	+ 8.2	-10.9	-14.7	+ 3.8	
8-21	- 9.6	- 8.3	- 1.3	- 7.3	-15.8	-17.0	+ 1.2	-11.2	-16.0	+ 4.8	-18.9	-22.0	+ 3.1	- 5.6
8-22	-14.2	-13.7	- 0.5	- 7.0	-15.6	-17.3	+ 1.7	- 8.0	-14.7	+ 6.7				- 9.6
8-23														
8-24	- 9.2	-17.0	+ 7.8	- 3.3	- 6.9	-13.9	+ 7.0	-10.0	-18.6	+ 8.6				- 2.6
8-25	- 6.9	-11.6	+ 4.7	- 4.5	- 4.5	- 8.7	+ 4.2	- 6.4	- 8.9	+ 2.5	-12.0	-12.2	- 0.2	- 2.4
8-26	-10.0	-15.2	+ 5.2	- 3.4	- 9.0	- 1.9	- 7.1	- 7.4	-16.0	+ 8.6	- 4.6	-12.2	+ 7.6	- 6.8
8-27														
8-28	-11.0	-19.0	+ 8.0	- 5.0	-11.5	- 5.9	- 5.6	- 9.9	- 1.9	- 8.0				- 7.1
8-29	-24.6	-22.2	- 2.4	- 5.2	-10.0	-15.2	+ 5.2	- 4.1	-10.9	+ 6.8				-10.5
8-30														
8-31	-19.4	- 3.2	-16.2	- 6.0	- 3.4	- 8.2	+ 4.8	- 4.1	- 8.3	+ 4.2				- 5.0
9-01	-20.0			- 8.4	-10.3	-14.3	+ 4.0	- 3.0	- 0.8	- 2.2				-16.5
9-02	-27.5	-18.3	- 9.2	- 8.3	-17.5	-16.9	- 0.6	-13.0	-16.0	+ 3.0				-16.4
9-03	- 2.9	- 8.5	+ 5.6	- 7.7	- 2.9	- 1.3	- 1.6	-12.0	-1.3	-10.7				
9-04				- 8.0	-11.0			-28.5	-24.2	- 4.3				-24.2
9-05				-10.3										-35.4
9-06	-16.1	-16.3	+ 0.2	-10.1	-29.2	-21.0	- 8.2							-16.0

Poa alpina Peatmoss-plus-Jute Net Plots

Field season leaf water potentials (ψ_ℓ), osmotic plus matric potentials ($\psi_\pi+\psi_\tau$), apparent pressure potentials (ψ_p), and soil water potentials (ψ_s). All measurements are in bars.

	Block 1			Block 2				Block 3			Block 4			
Date	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_s
8-09	- 9.1	-12.8	+ 3.7	-13.8	-16.5	+ 2.7	- 3.0	-10.6	-16.9	+ 6.3	- 6.6	- 8.7	+ 2.1	
8-10	-13.3	-17.0	+ 3.7	- 8.0	-17.0	+ 9.0	- 4.7	-10.3	-17.0	+ 6.7	- 9.6	-16.0	+ 6.4	- 9.3
8-11	- 5.0	- 4.8	- 0.2	-14.3	-16.6	+ 2.3	- 3.4	-12.2	-13.0	+ 0.8	-11.3	-15.2	+ 3.9	- 5.8
8-12	-12.7	-21.4	+ 8.7	-12.5	-20.0	+ 7.5		-14.0	-17.7	+ 3.7	- 9.0	-12.7	+ 3.7	- 3.4
8-13	-12.7	-15.7	+ 3.0	- 6.2	-11.8	+ 5.6	- 7.3	-12.9	-11.7	- 1.2				- 4.8
8-14	-15.1	-17.8	+ 2.7	-13.9	-13.1	- 0.8		-10.6	-20.2	+ 9.6	-13.7	-20.0	+ 6.3	- 3.5
8-15q	-11.2	-14.8	+ 3.6	-20.9	-23.1	+ 2.2	- 7.7	-17.8	-19.8	+ 2.0	-10.9	- 2.5	- 8.4	- 5.9
8-16	-12.0	-16.3	+ 4.3	- 7.9	- 6.9	- 1.0	- 3.2	- 3.7	- 4.7	+ 1.0	-14.6	-19.0	+ 4.4	- 3.0
8-17	-16.5	-21.6	+ 5.1	- 9.6	-15.4	+ 5.8	- 3.9	- 6.8	-18.6	+11.8	-11.3	-20.1	+ 8.8	- 3.6
8-18	- 6.0	-11.2	+ 5.2	- 7.4	-10.0	+ 2.6	- 3.1	- 3.2	-10.2	+ 7.0	-13.0	-18.7	+ 5.7	- 2.0
8-19	- 3.1	-15.2	+12.1	- 9.9	-23.0	+13.1	- 1.8	- 5.7	-16.7	+11.0	- 6.2	-15.0	+ 8.8	- 4.3
8-20	-13.0	-17.5	+ 4.5	- 9.2	- 8.9	- 0.3					- 9.4	-14.0	+ 4.6	
8-21	-12.5	-17.7	+ 5.2				- 8.3	-18.1	-20.1	+ 2.0	- 9.4	-15.0	+ 5.6	- 3.2
8-22	- 8.8	-16.0	+ 7.2	-14.3	-17.4	+ 3.1	-14.2	-11.2	-15.6	+ 4.4	-20.0	-19.0	- 1.0	
8-23														
8-24	- 4.2	-12.6	+ 8.4	- 9.2	- 7.0	- 2.2	- 5.0	- 6.4	-13.5	+ 7.1	- 2.3	- 8.3	+ 6.0	- 3.0
8-25				-11.7	-17.7	+ 6.0	- 3.0				-12.0	-20.2	+ 8.2	- 3.0
8-26	- 7.2	-11.0	+ 3.8	- 9.5	-15.4	+ 5.9	- 5.0	- 8.5	-17.1	+ 8.6	- 2.9	- 4.8	+ 1.9	- 2.0
8-27														
8-28	- 8.0	-13.0	+ 5.0	- 8.5	-17.6	+ 9.1	- 5.5	-15.0	-17.3	+ 2.3	- 6.0	- 8.8	+ 2.8	- 2.2
8-29	-15.8	-17.3	+ 1.5	- 7.9	-13.0	+ 5.1	- 6.9				- 1.9	- 6.0	+ 4.1	
8-30														
8-31	-14.0	- 2.2	-11.8	- 9.7	- 9.0	- 0.7	- 6.0	-13.3	-16.9	+ 3.6	-14.8	-15.7	+ 0.9	- 2.9
9-01	-18.9	-21.3	+ 2.4	- 6.2	-14.2	+ 8.0	- 7.1				-10.0	-15.6	+ 5.6	- 6.0
9-02	-22.2	-20.6	- 1.6	- 9.1	-15.9	+ 6.8	-11.4	- 6.9	-13.0	+ 7.1	-16.7	-16.7	0.0	- 4.0
9-03				-14.8	-16.8	+ 2.0	-13.5	-22.6	-22.6	0.0	-15.9	-18.7	+ 2.8	- 9.0
9-04	- 8.0	- 8.0	0.0	-19.2	-20.0	+ 0.8	-10.0	-15.0	-17.3	+ 2.3				
9-05							-11.2							-14.7
9-06				-29.5	-25.0	- 4.5	-17.5	-15.0	- 8.8	- 6.2	-12.4	-14.0	+ 1.6	

Alopecurus pratensis Growth Chamber Study

Growth chamber leaf water potentials (ψ_ℓ), osmotic plus matric potentials ($\psi_\pi + \psi_\tau$), apparent pressure potentials (ψ_o), and soil water potentials (ψ_s). All measurements are in bars.

	Block 1				Block 2				Block 3				Block 4			
Date	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_o	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_o	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_o	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_o	ψ_s
Control Pots																
10-15	-12.7	-12.5	- 0.2	- 1.7	-14.0	-12.4	- 1.6	- 6.9	-19.0	-20.6	+ 1.6	- 2.7	-12.1	-14.1	+ 2.0	- 4.6
10-16	- 2.1	- 1.0	- 1.1	- 3.6				-15.0	-12.3	-20.3	+ 8.0	- 6.0	-17.6	-20.7	+ 3.1	- 4.4
10-17	-13.7	-16.5	+ 2.8	-33.4	-45.4	-48.8	+ 3.4	-11.4	-27.8	-25.9	- 1.9	- 9.2	-10.7	-13.2	+ 2.5	-22.9
10-18	-17.9	-16.5	- 1.4	-13.2	-16.9	-17.0	+ 0.1	- 7.3	- 7.1	- 9.2	+ 2.1	-10.6	-29.1	-29.1	0.0	-21.2
10-19	-34.3	-31.0	- 3.3	-45.0	-37.4	-30.6	- 6.8	-10.7	-39.8	-31.9	- 7.9	-34.3	-21.3	-22.7	+ 1.4	
Peatmoss Pots																
10-15	-13.5	-20.0	+ 6.5	- 5.9	-14.3	-16.0	+ 1.7	- 3.0	-17.2	-15.9	- 1.3		-19.1	-20.4	+ 1.3	- 2.6
10-16	-11.7	-14.3	+ 2.6	- 8.2	- 9.3	-11.1	+ 1.8	- 3.7	- 2.7	- 2.7	0.0	- 2.7	-19.0	-19.4	+ 0.4	- 4.0
10-17	-15.4	-17.6	+ 2.2	-15.5	-20.9	-23.3	+ 2.4	-13.7	-28.7	-24.9	- 3.8	- 5.0	-35.0	-27.0	- 8.0	- 3.3
10-18	-13.0	-21.2	+ 8.2	-21.4	-12.8	-13.0	+ 0.2	-13.1	-15.0	-16.9	+ 1.9	-12.0	-13.6	-18.3	+ 4.7	-14.2
10-19	-33.6	-30.7	- 2.9	-41.8	-14.7	-12.1	- 2.6		-31.3	-23.9	- 7.4	- 5.0	-28.5	-21.6	- 6.9	-30.5
Jute Net Pots																
10-15	-11.0	-17.6	= 6.6	- 4.4	- 8.3	-16.0	+ 7.7		-10.0	-14.2	+ 4.2	- 5.3	- 7.1	-11.4	+ 4.3	- 1.8
10-16	-19.0	-17.6	- 1.4	- 3.4				- 9.2	-14.1	-18.4	+ 4.3	- 7.0	- 6.3	-21.8	+15.3	- 3.9
10-17				-12.3	-40.0	-37.3	- 2.7	-22.7	- 7.3	-11.7	+ 4.4	- 5.0	-28.0	-26 0	- 2.0	-15.8
10-18	- 5.0	- 8.8	+ 3.8	-17.0	-12.1	-21.2	+ 9.1		-13.4	-20.2	+ 6.8	-14.4				-25.5
10-19			-24.6						-17.7	-23.0	+ 5.3	-17.7	- 6.9	- 8.9	+ 2.0	-29.2
Peatmoss-plus-Jute Net Pots																
10-15	- 6.9	- 9.3	+ 2.4	- 3.7	- 7.6	-10.5	+ 2.9	- 1.5	- 1.2	- 3.0	+ 1.8	- 2.7	- 6.0	- 9.9	+ 3.9	- 2.2
10-16	- 4.4	-10.2	+ 5.8	- 4.8	-11.9	-18.3	+ 6.4	- 6.2	- 6.8	-14.5	+ 7.7	- 7.1	-11.3	-15.9	+ 4.6	- 8.1
10-17	-13.1	-18.7	+ 5.6	-13.7	-11.4	-20.9	+ 9.5	- 8.0	-18.3	-20.2	+ 1.9	- 9.4	-17.6			- 5.7
10-18	-11.0	-18.8	+ 7.8	-20.6	-14.6	-17.4	+ 2.8	-10.9	-11.9	-14.8	+ 2.9	-21.2				
10-19	-24.0	-25.8	+ 1.8		-30.2	-27.6	- 2.6	-13.0	-26.4	-21.7	- 4.7		-33.8	-28.2	- 5.6	- 6.7

Poa alpina Growth Chamber Study

Growth chamber leaf water potentials (ψ_ℓ), osmotic plus matric potentials ($\psi_\pi+\psi_\tau$), apparent pressure potentials (ψ_p), and soil water potentials (ψ_s). All measurements are in bars.

	Block 1				Block 2				Block 3				Block 4			
Date	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_s	ψ_ℓ	$\psi_\pi+\psi_\tau$	ψ_p	ψ_s
Control Pots																
12-4	-11.3	-15.0	+ 3.7	- 0.8	- 9.7	-11.6	+ 1.9	- 1.4	- 9.9	-13.0	+ 3.1	- 1.5				- 0.6
12-5	-14.7	-14.9	+ 0.2	- 2.0	-13.4	-17.0	+ 3.6	- 2.7	-11.2	- 9.6	- 1.6	- 0.4	-14.7	-12.1	- 2.6	- 1.4
12-6	-15.7	-16.7	+ 1.0	- 3.0	-16.0	-20.4	+ 4.4	- 2.3	-15.9			- 1.6	-12.9	-20.4	+ 7.5	- 1.7
12-7	-21.6	-24.2	+ 2.6	- 6.1	-24.0	-11.2	-12.8	- 5.0	-21.7	-20.9	- 0.6	- 7.3	-22.6	-21.8	- 0.8	- 1.0
12-8	-20.7	-18.2	- 2.5	-10.3	-23.6	-16.4	- 7.2	- 2.3	-43.6	-33.5	-10.1	-14.6	-17.4	-20.0	+ 2.6	- 4.4
12-9	-31.2	-27.9	- 3.3	-28.0	- 8.1	- 8.1	0.0	- 2.0	-24.4	-10.1	-14.3	-28.0	-20.0	-19.8	- 0.2	-23.9
Peatmoss Pots																
12-4	-13.0	-13.0	0.0	- 2.0				- 2.0				- 2.9	- 7.9	-10.8	+ 2.9	- 1.5
12-5	- 2.8	- 4.0	+ 1.2	- 4.8	-18.7	-19.6	+ 0.9	- 0.3	-11.7	-12.1	+ 0.4	- 8.4	- 1.3	-12.2	+11.0	- 2.7
12-6	-13.5	-11.8	- 1.7	-10.1	-17.5	-19.7	+ 2.2	- 3.0	-11.0	-14.3	+ 3.3	- 6.4	-19.6	-12.3	- 7.3	- 2.2
12-7	-25.0	-21.3	- 3.7	-21.7	- 5.1	- 4.0	- 1.1	- 5.7	- 3.7	- 6.4	+ 2.7	-15.2	-24.5	-21.3	- 3.2	
12-8	-48.7	-36.8	-11.9		-34.3	-25.9	- 8.4	-14.9	-22.6	-20.4	- 2.2	-43.5	-21.3	-22.2	+ 0.9	- 3.4
12-9				-27.0	- 6.0	- 4.1	- 1.9	- 2.0	-34.5	-21.0	-13.5	-36.9	-27.1	-23.8	- 3.3	- 1.0
Jute Net Pots																
12-4	- 6.6	- 3.0	- 3.3	- 1.6	- 1.9	- 2.5	+ 0.6	- 0.4	-11.9	-14.2	+ 2.2	- 0.7	- 5.7	- 6.1	+ 0.4	- 0.7
12-5	-22.7	-20.4	- 2.3	- 1.4	- 6.8	-10.3	+ 3.5	- 0.9	-12.9	-15.0	+ 2.1	- 2.7	- 8.1	-14.1	+ 6.0	- 2.3
12-6				- 2.3	- 4.1	-10.6	+ 6.5	- 1.4	-14.9	-10.6	- 4.3	- 1.7	-19.9	-20.5	+ 0.6	- 2.0
12-7	-15.0	-13.0	- 2.0	- 1.8	- 8.0	-16.7	+ 8.7	- 2.3				- 6.0	-14.6	-20.6	+ 6.0	- 2.0
12-8	- 5.3	- 5.5	+ 0.2	- 3.3	- 4.3	- 7.8	+ 3.5	- 1.9				-14.0	-11.6	-16.3	+ 4.7	- 2.2
12-9	-14.9	-14.9	0.0	-18.0	-12.3	-15.7	+ 3.4	- 3.5				-12.5	-25.6	-32.8	+ 7.2	- 3.3
Peatmoss-plus-Jute Net Pots																
12-4	- 9.0	-11.6	+ 2.6	- 1.0	- 4.3	- 9.5	+ 5.2	- 3.0	- 8.2	-13.6	+ 5.4	- 1.5	- 3.0	- 5.3	+ 2.3	- 2.0
12-5	-10.8	-13.0	+ 2.2	- 1.9					-12.0	-15.6	+ 3.6	- 3.0	-29.7	-22.4	- 7.3	- 0.6
12-6	- 7.5	-16.8	+ 9.3	- 3.5	- 9.4	-14.2	+ 4.8	- 3.2	-12.5	-16.9	+ 4.4	- 3.6	- 1.3	- 3.8	+ 2.5	- 1.6
12-7	-16.9	-21.0	+ 4.1	- 4.5	-17.0	-16.6	- 0.4	- 1.8	-22.9	-21.7	- 1.2	- 1.1	-20.3	-20.3	0.0	- 6.6
12-8	-19.1	-17.9	- 1.2	- 9.0	-12.3	- 9.1	- 3.2	- 3.8	- 8.8	- 5.8	- 3.0	- 3.0	-18.1	-18.1	0.0	- 7.6
12-9	- 4.0	- 4.0	0.0	-28.5	-28.5	-24.1	- 4.4	- 9.8	-18.0	-16.2	- 1.8	- 4.4	-23.0	-22.8	- 0.2	-30.1

Appendix B. Seedling measurements taken on August 30, 1976 in the field.

Seedling measurements taken on August 30, 1976 in the field. Abbreviations are as follows: *Alopecurus pratensis* = Alo; *Poa alpina* = Poa; Control group = C; Peatmoss = P; Jute net = J; Peatmoss + jute net = P + J.

Group	Block	Number of live plants	Number of dead plants	Dead/ live + dead	Minimum plant height (cm)	Maximum plant height (cm)	Most common number of leaves
Alo C	1	183	47	.2	1.5	2.5	3
	2	76	21	.22	1.3	3.0	3
	3	136	47	.26	1.5	2.5	3
	4	218	30	.12	1.5	2.5	3
Alo P	1	89	57	.39	1.0	1.5	3
	2	148	33	.18	1.3	2.5	3
	3	75	60	.44	0.5	1.2	2
	4	319	20	.06	1.5	3.0	3
Alo J	1	358	8	.02	1.5	2.5	3
	2	93	33	.26	1.5	2.5	3
	3	302	4	.01	1.7	3.0	3
	4	117	14	.11	1.5	2.5	3
Alo P + J	1	152	30	.16	1.2	3.0	3
	2	91	22	.19	1.3	2.0	3
	3	243	12	.05	1.5	3.0	3
	4	80	62	.42	1.5	3.0	3
Poa C	1	24	5	.17	0.5	1.0	2
	2	10	0	.0	0.5	1.0	2
	3	29	10	.26	0.7	1.0	2
	4	127	6	.05	0.7	1.0	2
Poa P	1	104	11	.1	1.0	1.5	3
	2	120	6	.05	1.0	1.3	2
	3	8	5	.38	0.5	0.7	2
	4	29	11	.28	0.5	0.7	2
Poa J	1	260	6	.02	1.0	1.5	3
	2	178	17	.09	1.0	1.5	3
	3	150	8	.05	1.0	1.3	3
	4	86	27	.24	0.7	1.0	2
Poa P + J	1	280	5	.02	1.0	1.5	3
	2	345	4	.01	1.0	1.7	3
	3	213	11	.05	1.0	1.7	3
	4	276	0	.0	1.0	1.7	3

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